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SUMMARY

A study was made to illustrate the utility of data obtained from an 11-band multispectral scanner at an aircraft altitude of 1.2 kilometers to describe the land-cover features of an abandoned surface coal mine. Color-classified images are presented of the statistical classification of data obtained during September and March overflights. There is a high degree of statistical and spectral separability for all land-cover features, even those within thematic categories such as barren land or water. The results of the study appear to be useful for planning the rehabilitation and reclamation of abandoned mines as well as for monitoring reclamation activity already in progress. The 1.2-kilometer aircraft altitude, with the corresponding 3-meter spatial resolution, is well suited for classifying barren spoilbanks and more than adequate for classifying undisturbed pasture and forest areas. However, it is marginal for classifying barren-bench and impounded-water areas. The accuracy of the statistical classifications was only qualitatively evaluated because the area was highly varied for the 3-meter spatial resolution and because it was difficult to relate the spectral separation between classes to real land-cover features. A statistical classification of the area from Landsat data is presented for comparison. Thermal imagery obtained during both day and night overflights is also shown.

INTRODUCTION

The disturbance of the Earth's surface by past and present strip-mining practices has altered and frequently damaged the surrounding environment. The ensuing environmental problems are many and varied and depend on factors such as geography, geology, mining practices, statutory regulations and their enforcement, and the reclamation practices that have been followed. The primary and longest-lasting effects of strip mining, however, are reflected in the pollution of the local watershed from mine drainage and sedimentation from the disturbed land. The mine drainage is typically acidic and is characterized by low pH and high mineral content, which can damage or even destroy the vegetative and aquatic life of the streams and rivers. The volume of sediment from strip-mined areas is generally much greater (as high as 1000 times) than that from undisturbed lands. The increased erosion and sediment load can result in choked streams, smothered stream bottoms, reduced light penetration, and damage to land and water transportation systems.

The principal methods of controlling the environmental effects of strip mines are suitable legislation, frequent and periodic inspection, and the implementation of adequate and long-lasting reclamation techniques. Ground inspection is essential to strip-mine control; however, it is frequently difficult and often inadequate because funding and manpower are limited. Inspection may be infrequent, especially for states with extensive disturbed areas. Thus state regulations are generally not totally implemented and enforced by any state. Remote-sensing techniques using photography or multispectral scanner systems from aircraft and, recently, satellites can complement ground inspection and may provide timely and useful data with synoptic and possibly even diagnostic capability.

References 1 to 8 are studies of the application of satellite data (namely, from Landsat and Skylab) for surface mines: They have found the data to be useful for detecting and locating surface mines with a disturbed area of at least 40 000 square meters. For large active mines of at least 400 000 square meters, satellite data may be useful for monitoring active mine operations as well as for recording reclamation progress. The techniques and practices of surface mining, however, are varied and complex; and the application of remotely sensed data to mining activities appears to be site specific and must be developed to satisfy the unique requirements of many different situations.

An aspect of surface mines that appears to be beyond the capability of using existing satellite (namely, Landsats 1 and 2) data is the reclamation or possible restoration of abandoned strip mines. These mines, which were generally mined 10 to 50 years ago before modern strip-mine laws and equipment existed, contribute substantial quantities of acid and sediment to the surrounding area and are a serious environmental problem especially in the Appalachian coal fields of the eastern United States. The U.S. Environmental Protection Agency (ref. 9) estimates that over 8 billion square meters of land are unreclaimed in the United States. The State of Ohio (ref. 10) estimates that there are 1.5 billion square meters of unreclaimed, abandoned mines in the State and that reclamation will require over $200 million and will take more than 25 years. The abandoned mines, particularly those in Ohio, are relatively small (4000 to 400 000 m^2) and have been contour mined, leaving a narrow (<100 m wide), meandering, grotesque scar that disfigures the surrounding area. Such a feature can be detected from satellite data; but it is difficult, if not impossible, to perform the analyses that are required to plan the restoration of the area from satellite data.

The restoration of an abandoned strip mine requires information regarding the physical condition of the area, the extent of earthmoving required, the drainage and probable acid condition, the spoilbank and soil conditions, and the general relationship of the mine to the surrounding area. Information of this extent must originate from numerous sources and requires the measurement of many parameters. High spatial resolution is generally necessary to develop an efficient restoration plan. One means of obtaining high-spatial-resolution data is by using a multispectral scanner mounted on an

aircraft flying at low to medium altitudes.

This report presents the results of a study of the utility of 11-band aircraft multispectral scanner system data for describing an abandoned strip mine in southeastern Ohio. Typical information that can be obtained from multispectral data is illustrated; the level of the difficulty involved in the analysis is indicated; some general interpretations of the application and limitations of the information are presented. No attempt is made to directly apply the data or to develop a detailed plan for the reclamation of strip mines. This is best left to reclamation specialists, who should recognize aircraft multispectral scanner data as a valuable tool for the reclamation of abandoned strip mines.

STRIP-MINE TEST SITE

The strip-mine site that has been studied is in Noble County, Ohio, and is the property of the Ohio Agricultural Research and Development Center (OARDC). The test site consists of 5 million square meters, of which approximately 1.6 million square meters were stripped in the 1950's. The area was given to OARDC by the Union Carbide Corp. and the Baker and Noon Coal Co. after mining in the area was completed. The test site is the focus of major research studies into reclamation techniques for strip-mined areas and is managed by the Eastern Ohio Resource Development Center (EORDC). The test site is typical of many abandoned mines in southeastern Ohio that were mined before the passage of modern strip-mining laws (in Ohio this was 1972) and also before the availability of modern equipment and strip-mining techniques.

The characteristics of contour mining and associated nomenclature are shown in figure 1. A "cut" is made into the hill; the overburden material is removed and deposited over the side of the hill to expose the coal seam along a level shelf, or bench. The width of the bench is governed by the economics of removing the overburden. The overburden is deposited over the downward side of the hill and forms the spoilbank, which consists of low-grade subsoil and rock and generally extends to the valley below. The cut into the hill follows the contour of the hill, hence the term "contour mining."

If reclamation is not done after the coal is removed, the resulting terrain consists of the undisturbed hilltop, precipitous "highwalls" 6 to 18 meters high, bench areas 15 to 30 meters wide, and spoilbank areas extending from the edge of the bench to the valley below. The exposed highwall, the bench, and the spoilbank are subjected to continual weathering and can be sources of considerable acid drainage. The highwall and spoilbank are also subjected to severe erosion and landslides and can be sources of extensive sediment loadings to the surrounding streams.

In 1974, a statewide inventory of all abandoned surface mines in Ohio (ref. 10) categorized the area in which the test site is located (watershed 33) as having high strip-

mine density and consequently high acid drainage. The watershed 33 area was classified as a "hot" module (ref. 11) and was ranked as the first priority watershed in the state for reclamation planning. The watershed is the source of over 13 600 kilograms of acid per day and substantial sediment that severely degrade the streams of the area and eventually discharge into the Ohio River 40 kilometers away. The primary tributary of the watershed is Duck Creek, which is one of three streams in southeastern Ohio that is classified as severely polluted (ref. 12).

A black-and-white aerial photograph of the EORDC test site at a scale factor of 24 000 is shown in figure 2 with the property boundary outlined. The test site is approximately 1.6 kilometers wide and 3.5 kilometers long and comprises 6 000 000 square meters. The site was contour- and auger-mined and contains approximately 13 kilometers of winding strip-mined bench areas and 1.6 million square meters of exposed, sterile spoil material. The spoil material is primarily sandstone and shale and is extremely toxic, with soil pH values ranging primarily from 2.5 to 4.5. The bench areas are from 15 to 90 meters wide and the highwalls are from 6 to 15 meters high. The spoilbanks are very rocky to stony, with slopes ranging from moderate to very steep. There are four deep, freshwater ponds in the area that are used for cattle watering and numerous, shallow, highly acidic impounded-water areas along the highwalls. The drainage streams for the area are also polluted, with pH values ranging from 3.5 to 4.5.

Within the mined area, many major research studies related to reclamation practices are in progress and include planting trees on spoilbanks, measuring acid and salt leaching from spoil material, establishing various types of vegetative growth, and judging the practicality of using sewage sludge and industrial fly-ash waste to improve toxic spoilbanks. A considerable amount of diverse activity occurs in the test site on a scale of 4000 to 10 000 square meters, which may be typical of future practices for the reclamation of abandoned mines. Such diversity and scale in land-cover features make the test site ideally suited for studying the utility of multispectral scanner data in analyzing and classifying the characteristics of surface mines for reclamation planning.

DATA ACQUISITION

The remotely sensed data were obtained aboard the NASA Lewis C-47 research aircraft. The data acquisition system consisted of the following items: (1) a Bendix Corp. 11-channel, modular multispectral scanner (M^2S), (2) a Fairchild KC-1B mapping camera with a 15.2-centimeter-focal-length metrogon lens that uses Kodak double-X aerographic black-and-white film, and (3) a four-camera array of 70-millimeter Hasselblad electric-drive cameras with either 50- or 80-millimeter-focal-length lenses. The film used was Kodak aerographic-plus black-and-white film, Kodak ektachrome MS

aerographic 2448 color positive film, Kodak aerochrome 2443 infrared color positive film, and Kodak aerocolor 2445 color negative film. The photographs were used as reference data for comparison with the multispectral scanner imagery and with the classification results.

The primary source of data, however, was the multispectral scanner (M^2S). The M^2S (ref. 13) is a rotating, flat-mirror, line-scanning instrument manufactured by the Bendix Corp. of Ann Arbor, Michigan. The salient features of the M^2S are summarized in figure 3. The scanner field of view (FOV) is 115^o ($\pm 57.5^o$ around nadir) with an instantaneous field of view (IFOV) of 2.5×10^{-3} radian. Each mirror revolution (or scan line) consists of 803 IFOV's or picture elements (pixels) with a nadir spatial resolution of 2.5×10^{-3} times the aircraft altitude; that is, at an altitude of 300 meters the spatial resolution is 0.75 meter.

The multispectral scanner measures reflected solar energy in seven visible wavelength bands and three near-infrared wavelength bands with silicon detectors. It also measures the emitted thermal energy from the Earth's surface in the 11- to 14-micrometer atmospheric window band with a liquid-nitrogen-cooled mercury-cadmium-tellurium detector. The scanner has manually set drift correction and a vertical reference gyro with instantaneous electronic roll compensation.

The detector signals are electronically conditioned, controlled, adjusted, and finally sampled and digitized with an eight-bit (0 to 255 digital levels) analog-digital converter. Each of the 11 channels of digitized scanner data is serially recorded on one of 14 tracks of high-density digital tape (HDDT) with 4000 bits per centimeter packing density in biphase-L pulse code modulation format.

The scanner motor, electronics, and tape recorder are synchronized, timed, and controlled by optical encoding signals from the scanner motor to generate an accurate, repeatable scan line (pixel by pixel) and an Earth scene (or image) by contiguous scan lines. The mirror rotation rate (or scan-line recording rate) is preset and matched to the aircraft speed and altitude. The mirror rotation rate is variable in integer increments over the range 10 to 100 revolutions per second. During each mirror revolution, 838 eight-bit data words are recorded per channel. Of these 838 words, 803 comprise the Earth scene, 22 words are used for calibration or identification, and 13 words are used for scan-line framing. For a 4000-bit-per-centimeter packing density, a scan line on high-density digital tape consists of 6704 bits of data and corresponds to 1.7 centimeters of magnetic tape. A single HDDT with 2200 meters of tape can record 129 000 scan lines of data, which at an aircraft altitude of 1.2 kilometers corresponds to a flight line 350 kilometers long.

The direct-current level and gain of the detector signal are controlled by four reference sources that are internal to the scanner and are sampled once during each revolution of the mirror. These four internal reference sources are (1) a low black-body temperature (or zero radiant energy source for the silicon detectors) supplied by a con-

trolled, liquid heat exchanger; (2) a visible radiant-energy source supplied by a controlled and calibrated tungsten lamp; (3) an additional visible radiant-energy source supplied by a fiber optic view of the sky; and (4) a high black-body temperature supplied by a controlled, liquid heat exchanger. These four sources not only provide the direct-current level and gain control, but also permit each scanner channel to be calibrated into irradiancy energy values or, for the thermal channel, into the equivalent black-body temperature.

The M^2S and recorder must be set up and operated with considerable care to insure accurate and useful data. Aircraft scanner data and aerial photographs were obtained on the flights shown in table I.

ANALYSIS

The primary analyses of the multispectral scanner data were made on the Bendix Corp. multispectral data analysis system (MDAS) (ref. 14). The MDAS is an interactive minicomputer analysis system specifically designed for the display, analysis, and supervised classification of aircraft and satellite multispectral data. The data are input on nine-track 315-bit-per-centimeter computer-compatible tapes (CCT) that are made (reformatted) from the HDDT obtained on board the aircraft. A CCT is limited to approximately 2000 scan lines of 11-channel data.

In the training-site-selection phase (or supervised classification mode), the CCT data are displayed in image form on a video display system from a density slice of a single channel of data or a false-color image created from a gray-level density slice of any three channels, with each channel assigned to one of the three (red, green, or blue) cathode-ray-tube guns of the video display. A cursor is positioned around a predetermined, distinguishable area of the display to select definable classes or groups. The areas and definable classes have been previously established from ground surveys or the interpretation of aerial photographs. The area within the four-sided polygonal cursor is referred to as a training site, and the 11 channels of multispectral data associated with each pixel within a training site are stored in a separate file and are designated as a specific class for later statistical analysis. Typically, a number of training sites will be selected to define all classes of interest for the specific classification. For the MDAS a maximum of 99 training sites can be selected and a maximum of 49 classes can be specified. (More than one training site can be used to define a specific class.)

After the training sites and classes have been established, the multispectral data are statistically analyzed for the mean value and standard deviation of each channel (i.e., the spectral signature of the class) for an assumed multivariate normal distribution of the class data. In addition, other statistical values or parameters that are of

importance to the MDAS analytical procedure, such as eigenvalues and processing coefficients, are evaluated and printed out on a line printer.

Generally a number of iterations are required during the analysis to discard, add, or modify training sites and to discard, combine, or add new classes to obtain a satisfactory set of training-site data. The training-site selection is finally verified by classifying only the training-site data into the appropriate classes. For general classifications, which include only a few general classes, at least 90 percent of the training-site data should be classified accurately. However, for more detailed classifications, such as those within a given theme (e.g., barren land or water) with little separability between classes - or for complex areas - an accuracy of only 60 percent may be acceptable. The final classification process is then an iteration and refinement procedure to meet the user's needs in terms of specific classes and desired accuracy.

The final phase of the analytical procedure is the production of the hard-copy image of the final classification. For this report, only two types of products were used: 35-millimeter color slides of the video image display, and a color composite image of the entire data tape generated by an Optronics color-image recorder. The 35-millimeter color slides are simply produced and inexpensive. The video image, however, is not rectified and introduces geometric distortions into the scene for pixels that are more than 200 pixels from the nadir. In addition, each video image has only 320 pixels and 240 scan lines and therefore presents only a limited view (less than 5 percent) of the total scene for one CCT. If the scene contained on an entire data tape is to be obtained from 35-millimeter slides, a mosaic of approximately 30 photographs must be made.

The Optronics color-image recorder provides an image of the entire data tape in rectified form in a 60-millimeter by 110-millimeter format. However, the spatial resolution of the Optronics image (20 pixels/mm) is approximately one-half that of the 35-millimeter slide image (10 pixels/mm). There is also some degradation in visual quality and color reproduction because of pixel overlap in the generation of the Optronics image.

DATA PRESENTATION

Results will be presented for analysis of the following:

(1) A 17-class classification of the general land-cover features of the mine area for a September scene

(2) A barren-land classification of the same September scene, which includes 16 different barren-land classes

(3) A barren-land classification of a March scene, which includes 15 barren-land classes

(4) Statistical analysis and spectral signature determination of surface-water areas

for the September and March scenes

(5) Qualitative evaluation of the utility of thermal-channel data for day and night scenes

(6) Comparison of aircraft scanner data with Landsat data

Only those results that pertain directly to the final classification are discussed in the main body of this report. The ground-survey data, training-site characteristics, and intermediate statistical data that are important only during the classification process but provide insight into the applicability of the analysis are presented in appendixes A to D. The appendixes contain the following:

(1) Aerial photographs showing the locations of training sites

(2) A tabular description of the training-site characteristics and the class (or group) assignments

(3) A tabular list of the statistical data and the spectral signatures of the different classes

(4) Some general discussion pertinent only to the analysis of the data

RESULTS AND DISCUSSION

A number of data acquisition flights were made over the test site during a 2-year period. The data and results of a few of the overflights are presented to illustrate the utility of aircraft scanner data in characterizing the land-cover features of abandoned strip mines. The results emphasize primarily the analysis and classification of September and March overflight data obtained at an altitude of 1.2 kilometers. Other overflight data are presented as required to illustrate specific points.

Figure 4 is a typical single-channel computer image of the test area that was produced from scanner data obtained at an aircraft altitude of 1.2 kilometers. The image was produced from channel 7 data (center wavelength, 0.68 μm) and resembles somewhat a panchromatic photograph (fig. 2). The image contains the entire scene of one complete CCT and consists of approximately 2200 scan lines of data. The scale factor of the figure 4 image is 24 000, and it is a 2.5-times enlargement of the original negative generated by the Optronics film recorder. The Optronics image is constructed point by point, has been rectified (i.e., corrected for scanner "look angle" distortions) by point replication, and can be compared reasonably well with an aerial photograph or a topographic map. (See appendix F for discussion of image rectification.) The image rectification, however, is only approximate because of topography and aircraft motion, and an accurate overlay between the image and a map cannot be obtained over the entire image area.

With experience, conventional photointerpretive techniques can be used to qualitatively evaluate the single-channel image. In figure 4, the barren areas and haul roads

are white to light gray, the undisturbed pasture and agricultural areas are light to medium gray, and the forested areas are dark gray for hardwoods to black for evergreens. The surface-water areas range from light gray to black. Similar black-and-white images can be generated for all 11 scanner channels.

The 1.2-kilometer aircraft altitude at which the data were obtained is well suited to the general analysis of the mine characteristics and provides a useful working format upon which to base the training-site selection for analysis and classification of the data. The 3-meter scanner spatial resolution (IFOV) at the 1.2-kilometer altitude is more than adequate for interrogation of the data for the vegetated and barren spoilbanks. However, the spatial resolution becomes marginal for studying parts of the barren-bench and impounded-water areas and is totally inadequate for studying the small streams and drainage patterns of the area.

A typical cursor outline to describe a training site is shown in figure 5. The image was photographed directly from the MDAS video display with a 35-millimeter camera. The cursor location is shown for the sandstone-spoilbank training site (SP1c) of appendix A and is displayed over the final classification of the data in figure 5. The figure illustrates the detail of the MDAS display, the relative homogeneity of the data within the cursor (training-site data) as required for good training-site selection, and the varied color classification that can occur near a training site. The pixel-by-pixel quality of the display is evident in the photograph.

Generally, training sites consist of 100 to 300 pixels for undisturbed vegetated areas, 50 to 150 pixels for barren areas, and 10 to 50 pixels for water areas. Training sites of this size are adequate to obtain a valid statistical sample. However, the training-site location must be established with extreme care, especially for the complex barren land areas, where graded and ungraded areas can be in close proximity or where sparsely revegetated areas and barren areas are indistinguishable. For this study, training sites were selected from a single-channel, color-density slice or a three-channel, superposition, false-color display. A single channel or the combination of three channels could not be used for the selection of all the training sites. A variety of data channels was required throughout the training-site selection process to insure the accuracy of the data.

September Land-Cover Classification

The first study was a general level I land-cover classification of the mined area into different classes. A general classification such as this is simple and straightforward and may be adequate for reclamation planning and monitoring. The final product of the study is shown in figure 6 and table II. Figure 6 is the final computer-classified color image of the entire area into 11 colors. Table II summarizes the classification

in tabular form and also includes the percentage of the area assigned to each color and each class. Specific data related to the selection of training sites and classes and some of the more pertinent radiometric and statistical data are presented in appendix A.

Figure 6(a) compares a typical Optronics color-coded classified image of the data contained on a complete data tape with aerial photographs of the area. The image has been geometrically rectified by point replication and is presented at a scale factor of approximately 36 000, which is a 1.7-times enlargement of the original Optronics image. Figure 6(b) is a 5-times enlargement (12 000 scale factor) of the southern part of the image and can be more readily compared with the aerial photograph of the area presented in figure 7. A scale factor of 12 000 is the most suitable scale for the general review of the image products for various mine features.

An attempt has been made to use approximately true-color coding of the classified image in order to maintain some correspondence with color photography. However, false-color coding is necessary to provide the contrast required to discriminate between various classes. The color coding consists of the following: green, undisturbed natural vegetation; yellow, revegetated areas; blue, water; gray, graded bench areas suitable for farming; pink, ungraded sandstone spoil areas; and dark gray or purple, graded or ungraded shale spoil areas. This color coding is maintained throughout this report with only slight modifications.

The general surface features of the strip-mined area easily discerned in the color images. The 11-color representation of the area, however, provides, at best, only an approximate description of the many varied and complex surface features. To establish the utility and limitations of the classification, we must evaluate the color-classified image in terms of the training-site selection, the grouping of training sites into classes, and the eventual combining of classes into colors. Table II and appendix A are included for this purpose.

A useful aid for evaluating the classified image is shown in figure 8. Figure 8 is a two-channel representation of each feature class as an ellipse: The mean sensor values of channels 6 and 9 have been used to locate the ellipse center, and the standard deviations have been used to establish the major and minor axes of the ellipse. A representation such as this is not a thorough description of the interaction between the various classes. However, the figure is informative, establishes a correspondence between the various classes, and indicates to some extent whether similarity or confusion can exist between various training sites and classes. A two-dimensional representation such as this will describe in only a very conservative manner the level of separation that actually exists between different classes for multichannel data. The figure, however, is useful as a convenient basis for making systematic decisions, during the analytical process, regarding class groupings or the similarity of various training sites or classes.

In the two-channel representation of figure 8, channels 6 and 9 were used because

they are the two channels most suitable for the analysis of land cover from scanner data. (See table VI for the best four channels for discerning each class.) The wavelengths associated with channels 6 and 9 correspond to bands 5 and 6 of Landsat data, which are the most suitable data for band-ratio analyses to locate and detect strip-mined areas (ref. 6). The suitability of using the band-ratio technique for Landsat bands 5 and 6 is evident by the good data separation of the various classes in figure 8 and the linear alinement of the barren-land data. The primary limitation of the band-ratio technique, however, is the possible confusion between barren land areas and water areas, as indicated by the alinement of the shallow- and deep-water classes and the intersection with the barren-land class line. A further limitation of the band-ratio technique is the inherent alinement of the barren-land ellipses, which makes the separation (or thematic classification) of the barren areas into distinct classes somewhat difficult.

The overall accuracy of the final classified image is hard to specify and only a qualitative assessment is made for each analysis. More detailed images are presented in the section Detailed Evaluation and Comparison of Classifications for three subareas of the site. The images can be used for further evaluating classification accuracy. The following general comments, however, apply: The "trees" group (dark green) includes hardwoods, evergreens, and black locusts. The color-classified image closely duplicates the forested area in the aerial photographs. Even an apple orchard and a small peach orchard can be detected by the pattern of the colored single trees. The three tree classes (1 to 3) are an acceptable representation of the forested area even though the radiometric data range associated with the forested area, as indicated by the channel 9 data, is quite large. The channel 9 data for trees range from 95 counts to 230 counts; the channel 6 data range from only 20 counts to 32 counts. For the September scene, the large channel 9 range corresponding to the near infrared (IR) wavelength range indicates the start of stress conditions, primarily for the hardwoods, and the start of the fall season. The percentage of the total area for each class indicated in table II is in good agreement with the actual scene.

The "pasture" group (medium green) includes three classes (4 to 6). Variations within the pasture area also appear to indicate "stress" conditions. There is some confusion between the pasture color classes and the class 9 revegetation II color class (dark yellow), especially on the north- and west-facing slopes. The pasture misclassification as revegetation II is the most serious error of the classification. The revegetated II class (~90 percent reclaimed) frequently appears in pasture areas; however, the pasture color rarely appears in a reclaimed area. The high percentage of the total area classified as class 9 in table II includes much undisturbed pasture area. Additional training sites in the misclassified areas would have eliminated this problem.

The agriculture class 7 (light green) is only a fair representation of the area. There is some confusion between revegetation I (class 8) and agriculture. This, however, was not unexpected. Both classes represent a composite of stressed vegetation (recently

cut) and barren land areas. Classes 4 to 9 are all similar in that they represent varying degrees of vegetation and barren land areas. This similarity is indicated by the close proximity of the ellipses in figure 8. The discrepancies evident in the color image are considered not as a serious limitation of the analysis but rather as a true representation of the infinite variability of the vegetated cover of the area and the inaccuracy inherent in using a limited sampling technique to describe the differences between the various vegetated areas.

The water classes 10 and 11 (light and dark blue) locate most of the water areas that are detectable within the spatial resolution of the scanner. Three shallow-water and six deep-water training sites were used to insure that adequate statistics were available to include most of the water types. During the analysis, there was confusion between the deep-water class and highwall shadows. The possibility of such confusion is evident in figure 8. The inclusion of a shadow class eliminated this problem.

The barren land areas of abandoned mines are of primary interest for reclamation and received the most attention during the classification. Many training sites were selected, combined, and/or disgarded to determine the extent of separability between classes and to insure as complete a representation of the barren land areas as possible. Basically the barren land areas were represented by three colors: White was assigned to the regraded sandstone bench areas, red to the ungraded sandstone spoilbank areas, and gray to the regraded or ungraded shale areas. In figure 8 these three classes are well separated by channels 6 and 9, as indicated by the ellipses of classes 12, 13, 15, and 16. Much of the barren land areas of the mine, however, are not homogeneous but rather of a complex and nonuniform composition. The regraded bench areas were the most difficult to classify because of the combined sandstone and shale composition of most of these areas. Class 14 was introduced to handle this mixture of sandstone and shale. The varying composition of class 14 is indicated by the large ellipse (large standard deviation) even though the number of pixels (154) was not great. The white, red, and gray areas are considered a good representation of the barren land areas if the combined areas of the three classes are used to represent a level I barren-land classification. The capability of each of the three barren-land classes to separate the barren land areas accurately is estimated to be only fair. Much of the bench area, which is a combination of shale and sandstone, was classified as sandstone spoil rather than sandstone bench. The shale spoil representation is considered to be good. The inherent difficulty of accurately classifying the barren land areas into three colors is due to the large radiometric range that is characteristic of the barren land areas, as indicated by the data count range of 65 to 190 counts for channel 6 and 70 to 180 counts for channel 9. The attempt to cover such a large radiometric range with only three colors is an oversimplification of the land cover and results in an image that is much too uniform in appearance. Many more classes and colors are required in the barren land areas to produce a classified image that describes the various land-cover features accurately. The following analysis

attempted to rectify this problem by including many more barren-land classes and colors.

September Barren-Land Study

The September data were analyzed to achieve a more detailed classification of the barren land areas. The final products of this analysis are presented in figure 9 and table III. The channel 6 and 9 representation of the class ellipses is shown in figure 10, and the radiometric and statistical data of the training sites and classes are presented in appendix B. The barren-land thematic classification of the data was more difficult and required considerably more time and effort than the general land-cover classification. For this analysis, 49 training sites, which included 18 barren land areas, were used to define 27 classes. Seventeen of the classes were barren land. A total of 18 colors were used, with 11 colors representing barren land areas. The vegetated and water areas of this classification were similar to those in the previous classification. No attempt was made to improve the classification of these areas. The vegetated classes were included in the analysis so that there would be enough classes to properly describe the area and so that the final color image could be conveniently interpreted and compared with aerial photographs or with the other classified images of the area.

The two primary results of the analysis are best indicated in figure 10. First, introducing the shale bench areas (classes 4 and 5) extended the bench classes into the lower radiometric data range previously allocated to the sandstone spoils. The result is that more of the barren land area is classified as bench than in the previous classification (table II). The increased bench area more closely corresponds to the actual physical characteristics of the mine area. Second, the five sandstone spoil classes clustered into a tight group in the plot of channel 6 versus channel 9, indicating a high degree of similarity between these classes. The differences in the physical characteristics of the sandstone spoils were difficult to detect even from large-scale-factor aerial photographs. Ground surveys and soil maps were required to label the different spoil classes. The training-site data for the spoil classes showed reasonably tight clusters (i. e., high eigenvalues in table VIII). However, the classification accuracy values in table VIII for the training-site data show confusion with other classes, as might be expected for these complex spoil areas.

In the final color image, the bench classes are represented by five colors: white, three levels of grey, and brown. The brown class (5) represents a significant 8.47 percent of the total area and almost one-half of the total barren land area. This high percentage is reasonable since much of the barren land area has been graded. The color image of the barren bench areas is consistent with aerial photographs and ground surveys. The five colors produce a complex and varying image that is very representa-

tive of the actual mine.

The ungraded sandstone spoil areas are represented by only two colors, even though five classes were used in the analysis. The two colors that were selected are pink and light purple, colors that can be separated in the image and still denote a similarity that is typical of the physical features of the spoil classes. The graded or ungraded shale spoil areas were separated into four classes (11 to 14); three colors (red, purple, and dark purple) were used to represent the areas. These areas are easily separated statistically and can be readily located within the color-classified image.

The overall color classification of the barren land areas is considered a good representation of the actual site. The classification of the bench areas, in particular, indicated the many varying characteristics of the site and the difficulty inherent in describing the strip mine in simple terms, as was attempted in the land-cover classification.

Three small experimental test sites that are being used to evaluate the utility of fly-ash and sewage sludge (classes 15 to 17) for reclamation were included as distinct classes in the statistical analysis but were not displayed separately in the color image. These classes, because they accounted for only a very small part of the total area, were combined into other color groups to minimize the number of colors for an interpretable color image. A higher degree of class separability could have been included in the color image; however, the increased confusion would have detracted from the final image.

March Barren-Land Study

The final products of the March analysis, which also emphasized the classification of barren land areas, are presented in figure 11 and table IV. The two-channel (channels 6 and 9) representation for all the classes is shown in figure 12. The training-site descriptions and the radiometric and statistical data are included in appendix C.

The March analysis consisted of 35 training sites, of which 15 were barren land, and 26 classes, of which 15 were barren land. Twenty colors were used in the final product, with 12 colors used for barren-land classes. The final color-classified images in figure 11 are easily related to the aerial photographs of the area.

The March data proved to be more difficult to analyze than the September data. The March data were obtained on an overcast day with a uniform layer of high-level clouds at 4.5 kilometers. The weather was cold, with air temperatures of about 274 K (35° F). The ground surface was damp from the March thaw. The overcast condition was considered to be ideally suited to the study of strip-mine areas in that elevation and surface slope effects and the need to consider highwall shadow were eliminated. The damp surface conditions, however, introduced considerable difficulty in training-site

selection, primarily for the bench areas. There drainage differences were significant and surface reflectance varied greatly in an apparently uniform area. It was necessary to use small training sites of less than 50 pixels to insure reasonable uniformity.

During the analysis, difficulty was also encountered in selecting suitable training sites to describe the hardwood trees, which lacked foliage in the spring. Despite this problem, the forested area compared favorably with the September classification of the data and also with the aerial photography.

An attempt was made to improve the land-cover classification of the area by more accurately representing the undisturbed vegetated area. The two revegetated classes (22 and 23), however, again presented some classification problems. The statistical data for these classes, as indicated by figure 12, somewhat resembled both barren areas and undisturbed vegetation. Misclassifications frequently occurred in high-stress areas of undisturbed vegetation such as along roads, paths, drainage gullies, and stream banks and in high cattle-grazing areas.

An agricultural class was not included in this classification because there was no legitimate training site.

The two water classes have some intraclass misclassifications, but the representation of all the water areas is quite complete. The colors used for the March image provided much better contrast than the September image. The water areas shown in figure 11(a) along the highwalls and in the valleys duplicate almost exactly the actual water area, even for very shallow impoundments and drainage streams.

The accuracy of the barren-land classification for the March data is difficult to evaluate. Considerably more area is classified as sandstone spoil than actually exists. Much of this difficulty is attributed to the dampness of the bench areas, which results in lower radiometric levels because of lower reflectance. Figure 12 indicates, to some extent, the possibilities of overlap between the various classes. The sandstone spoil classes in the March data did not cluster tightly together as they did in the September data. Rather the six different sandstone spoil classes (the ellipse in fig. 12) separated quite well from each other but did overlap quite significantly with the bench classes and to a lesser extent with the shale spoil classes. The large data range over which sandstone spoil classes are defined is desirable for analysis but probably has resulted in the overclassification of these classes. The overcast sky is believed to have improved the separation of the spoil classes, as did the larger number of training sites.

Detailed Evaluation and Comparison of Classifications

The general comments made, thus far, on the utility and limitations of the analysis have been consistent with the image presentation. These comments, however, do not exploit the 3-meter spatial resolution of the scanner data nor do they favorably illustrate

the capability to provide the detailed information required for the reclamation of abandoned strip mines. Additional imagery is presented for the three subareas of the strip mine so that the use of scanner data can be more critically reviewed, evaluated, and compared. The three subareas are shown in figure 13 and illustrated different aspects of abandoned-mine features. The image products for each area include a natural-color and color infrared aerial photograph and the classified images for the three analyses. All five images of each area are presented at a scale factor of approximately 18 000. The discussion of each area is intentionally limited to only a few comments to eliminate frequent repetition. The final evaluation of the results must be left to the reader - to correspond to his level of interest and possible application.

Subarea 1. - Subarea 1, shown in figure 14, is an example of hilltop-removal mining where significant regrading and reclamation are in progress. The barren areas consist of soil types ranging from fine regraded sandstone to regraded shale. There are no steep spoilbanks in this subarea. The revegetation success ranges from 0 to 100 percent and also includes moderate reclamation success with black locusts. The subarea includes a very shallow water area and a black-water pit.

For the areas shown in figure 14 the September land-cover classification is a good, though only a very general, representation of the area. The most serious misclassification is for the black-water pit. In the September barren-land study the barren-area classification is excellent. The variability of colors indicates the complexity of the barren areas. The revegetated-area classification is also good. The shallow water area, however, is misclassified and the black-water pit is less than 50-percent accurately classified. The March color-classified image shows the range of diversity in the barren land areas. A more suitable coloring arrangement might have enhanced the image. There is considerably less revegetation in the reclaimed area, but this is to be expected in March. Both the shallow water area and the black-water pit are accurately detected. In fact, the main drainage stream in the lower portion of figure 14 is also evident.

Subarea 2. - Subarea 2, shown in figure 15, is a typical contour-mined area where considerable regrading and reclamation are in progress. The difference between the sandstone and shale areas is visible in all three images. The September barren-land study is a particularly descriptive image of the area. The most serious misclassification is the wetland area, which was incorrectly classified in all three images.

Subarea 3. - Subarea 3, shown in figure 16, is also a typical contour-mined area; however, the benches are quite narrow, the sandstone spoils are quite large, and the reclamation activity is very limited. The September classifications are good; however, in the March classification, some of the bench area has been misclassified as sandstone spoil.

The conclusions that can be drawn from these images are as many and varied as the scenes presented. The most obvious conclusion is that the land-cover features of

abandoned mines can be described and classified in detail from aircraft scanner data. However, the time and effort required to obtain a useful classification increases as more detail is required.

The general, 17-class land-cover classification required approximately 25 hours of computer time for the analysis; the September barren-land study required 30 hours; and the March barren-land study required 35 hours. The September barren-land study is the most descriptive of the area except for the revegetation/pasture land misclassification. The March barren-land study is the most difficult to evaluate in terms of overall accuracy because of the damp soil areas.

The selection of the colors for the final color-classified image was a critical part of the analysis. Information can easily be lost if a poor color selection is made. Sixteen to 18 colors are a maximum useful number to maintain good discrimination between classes and to present an uncluttered image.

Comparison to Landsat Imagery

A view of the strip-mined area from the Landsat satellite data is shown in figure 17. Figure 17 is a three-channel, false-color representation of the area as obtained on the Bendix MDAS display system. With familiarity, the mined area can be located in the image and some of the general features of the mine can be distinguished. The white and blue correspond to barren land areas; the yellow, green, and red correspond to vegetated areas; and the dark red to black corresponds to forested areas. The various colors show that some degree of class separation is possible. Attempts at a supervised classification of the area on the MDAS system were unsuccessful because problems were encountered in establishing training sites because of satellite spatial resolution and the variable surface features in the area.

Further attempts to classify the area from Landsat data were made with the LARSYS III (ref. 15) analysis system and a Univac 1110 digital computer. The LARSYS III system is somewhat more suited to the detailed study of small areas of satellite data but requires considerably more time. Figure 18(a) is a dot printer output of the Landsat band 5/6 ratio and displays the barren land areas. The printout is an acceptable representation of the area. The overall test site consists of a Landsat image that is 40 pixels wide and 50 scan lines long. The results of a supervised LARSYS classification of the area are shown in figure 18(b). There is no doubt that satellite data can be used to detect mines of this size. However, the utility of the Landsat pixel size (57 m by 79 m) to provide the spatial resolution required to study the various surface features for reclamation planning is questionable.

Surface-Water Study

The serious and extensive problems associated with acid drainage from abandoned mines warranted further study into the surface water of the area. Two additional studies were made to extract only the sensor radiometric data and to compare the reflectance characteristics of the various water areas in order to determine whether further subclassification of the water areas would be possible and useful for describing water parameters. The first water study considered the September data. The locations of the training sites and the radiometric and statistical data for 24 water test sites are shown in appendix D. The pH data of samples obtained during ground surveys are also included.

The data indicate a considerable range in the reflectance characteristics of the water surfaces. In fact, no two water training sites appear to be identical. This result is clearly illustrated in figure 19, where the two-channel representation for the water training sites using channels 3 and 7 (two channels that are suitable for water) are shown for all 24 training sites. The data in figure 19 are not shown as ellipses but by symbols that separate the data into groups with pH > 4 and pH < 4 as determined from sample measurements. The standard deviations of the water training sites are small ($\lessdot 4$) because of the small sample size and the uniform water areas. The symbol size that is used approximately represents the standard deviation in the data. Figure 19 also includes (as ellipses) the water training-site data used for the September barren-land analysis. There is an indication of a possible correspondence between low pH and high radiometric values. The correspondence, however, is probably more directly related to water depth than to pH.

The 1.2-kilometer aircraft altitude of the September overflight was slightly high for the spatial resolution required to obtain data for all the water areas, including the drainage streams. To study the streams and smaller impoundments we analyzed the data obtained from a March overflight at an altitude of 0.6 kilometer. The radiometric and statistical data for the 19 training sites are shown in appendix E. The channel-3-versus-channel-7 representation is shown in figure 20. Only the southern portion of the test site was studied (all that could be included on one computer-compatible tape) at this low altitude. The March data show considerably more variation in reflectance than did the September data. The sediment-laden stream, in particular, extends the water reflectance into the high radiometric range much beyond that of clear, shallow, impounded water and explains, to some extent, the difficulty encountered in attempting to classify the stream from the few water training sites previously used.

The water pH data for the southern part of the strip-mine area also indicate significant differences from the trends in figure 19. Considerably more study is required of the water characteristics before any conclusions can be made.

Thermal-Channel Data

The data obtained on the thermal channel (channel 11) of the multispectral scanner have not been used for any of the classification analyses. The data obtained on the thermal channel are passive measurements and depend on the energy emitted from a surface rather than on the reflected solar energy that is measured by the other 10 channels. The thermal-channel data were included in the initial phases of each classification; however, the data were generally discarded during the final phases because they did not contribute significantly to the statistical classification.

Thermal-channel data, however, can provide useful information and have been studied for many years for various geological applications (refs. 16 and 17). The thermal-channel data are a measure of the temperature and emitting characteristics of a surface and therefore, within certain limitations, can be used to differentiate between various land-cover features. Furthermore, because they do not depend on incident solar energy, thermal-channel data can be taken at night.

Figure 21 presents both day and night thermal images for the strip-mine site at a scale factor of 24 000. These images can be compared with the aerial photographs of the site and the channel 7 image shown in figure 4. The day thermal image resembles somewhat a conventional black-and-white photograph in that there is a range of tone and texture. The night thermal image, however, is distinctively different and cannot be misinterpreted as a photograph.

With experience a qualitative interpretation of the black-and-white thermal images can be made by photointerpretive methods. Approximate temperature measurements, primarily of water areas, can also be made. The temperature ranges of the two images are 10° to 30° C for the day thermal data and 5° to 20° C for the night thermal data. The temperature ranges correspond to the 12 gray levels used to construct the images, with the temperature increasing from black to white.

In the day thermal image the barren land areas that are particularly highly absorbing, such as the dark shales, are white (high temperatures), the vegetated pasture areas are light to medium gray (intermediate temperatures), the forested areas are dark gray, and the water areas are black (low temperatures). In the night thermal image the water areas are white (high temperatures), the vegetated and barren areas are medium gray (intermediate temperatures), and the valleys are black (low temperatures). The night thermal image is particularly useful for delineating the water areas (white) and the valley areas. These areas can be used to describe the drainage and watershed characteristics of the area.

The thermal-channel data can also be color coded by a density slice of the data to provide increased contrast, enhanced temperature separation, and improved separation of land-cover features. Parts (c) and (d) of figures 22 and 23 are color-coded thermal images of subareas 1 and 2 and correspond to the scenes in figures 14 and 15. The

color bar shown corresponds to the color hierarchy that was selected. Each of the 24 color levels corresponds to temperatures of approximately 1.5 degrees F for the day thermal data and approximately 1 degree F for the night thermal data.

In the day thermal color image the water areas are gray (low temperatures); the black, highly absorbing, graded shale spoils are red/pink (high temperatures); and the vegetated areas are green/blue (intermediate temperatures). These generalizations are qualitative interpretations, however; and care must be exercised in making these interpretations because day thermal imagery is influenced by sun angle, terrain slope and elevation, moisture level, and wind conditions. Local variations in these parameters can significantly influence the temperature of a particular surface feature from location to location even within a small area.

In the night thermal color image the water areas are white/yellow (high temperatures); the vegetated areas are blue (low temperatures); and the black, regraded shale spoils are pink/red (intermediate temperatures). Again the generalizations are very qualitative and can be altered by such effects as elevation, terrain, wind, and time after sunset, all of which are important variables that affect surface temperatures at night.

The use of thermal data to describe the characteristics of strip mines is at a very qualitative and exploratory stage. At present these data are used primarily to detect impounded water or to identify drainage patterns.

CONCLUDING REMARKS

The study presents the results of three different statistical classifications of aircraft multispectral scanner data obtained at an altitude of 1.2 kilometers during September and March. The study concentrated primarily on the identification and separation of barren land areas in various classes such as shale and sandstone bench and spoilbank areas. The vegetated and water areas are also included in the analysis but received less attention.

The 3-meter spatial resolution of the data that corresponds to the 1.2-kilometer aircraft altitude was suitable for selecting good training sites for analyzing the barren land areas and was more than adequate for studying the undisturbed pasture and forested areas. In fact, aircraft altitudes in excess of 3 kilometers with 7.5-meter spatial resolution would have been acceptable. The 3-meter spatial resolution, however, was marginal for studying impounded-water areas and was totally inadequate for analyzing streams and drainage ways. It is recommended that 1.5-meter resolution be used for future studies of impounded-water areas and that less than 1-meter resolution be used for analyzing of streams and drainage ways.

The September classification best represents the barren land areas. The increased spectral signature contrast between the vegetation, water, and barren areas made the

selection and location of training sites easier and made the grouping of training sites into classes more predictable and reliable. The classification of the September scene into five bench classes, five sandstone spoil classes, and four shale spoil classes is a reasonable representation of the complex nature and variability of the area.

The March classification of the barren areas was more difficult and less predictable than the September classification. The problems encountered in the March study were attributed (1) to an overcast sky, which minimized contrast between surface features, and (2) to surface dampness of the barren areas. These two factors made training-site location and selection difficult. The dampness of the bench areas altered the spectral signatures and caused confusion and overlap with the better-drained spoilbank areas. The March classification of the pasture areas presents a better separation between undisturbed pasture and reclaimed areas than did the September classification. Because of the lack of foliage the March classification of the forested area was troublesome; however, the result is considered a good representation of the area.

The two-channel representation (channel 6 versus channel 9) of the various classes was a useful aid for combining or discarding sites and for assigning classes and colors. During the interactive computer analysis, the plots served as a simple representation of the class groupings and provided a systematic basis for decisions regarding the utility of various training sites and classes.

The two-channel representation of the water areas (channels 3 and 7) showed the large range and variability of the impounded-water and freshwater data. Limiting the water classification to only shallow and deep categories is questionable, but the detection of all water areas is considered quite complete. The sediment-laden primary stream of the area is the main uncertainty. The sensor data are much higher for the narrow stream than for the shallow, impounded-water areas; and the spatial resolution of 3 meters prevented a stream training site from being selected. The stream is easily located in the March classification but is classified as a spoilbank in the September classification.

The undisturbed pasture and revegetated areas are confused in all three classifications. This is not considered a serious limitation but rather a result of the lack of emphasis placed on the vegetation classes during the analysis. The vegetation classes were included primarily to provide a proper image product of the final classification, and attention was directed at reclaimed areas rather than at the undisturbed pasture areas. Additional computer time would have been required to classify the vegetated areas more accurately.

The classification of the Eastern Ohio Resource Development Center test site by using Landsat data was difficult because of the spatial resolution (57 m to 79 m) of the satellite data and the problems involved in selecting and locating training sites to describe the land-cover features of the mine. The band ratio (channels 5 and 6) technique applied to Landsat data was useful in delineating the barren areas for inventory and in

selecting and locating training sites. Care must be used in applying the band-ratio technique, however, because barren land and water areas can be confused. The statistical classification of Landsat data presented some difficulty and is included for comparison only.

The night and day thermal imagery was useful in locating shallow impounded-water areas and shale spoil areas. The night thermal data were especially useful in detecting water areas, in identifying drainage patterns and watershed boundaries, and in eliminating confusion between impounded-water and highwall shadow areas during the verification phases of the classification. As with any single-channel image, the interpretation of thermal imagery is only qualitative, and significant confusion can occur between various surface features.

In general, aircraft multispectral data can be analyzed to provide details, required for reclamation planning, of many surface characteristics of abandoned strip mines. Many simple as well as complex analyses can be made, and a variety of images can be produced that can provide information on many aspects of strip mines. The use of scanner data, however, is still in the formative stages. The analysis and final products are highly subjective; and the final products are governed by the objectives of the study, the experience of the analysts, and the time and effort devoted to the study. In the final evaluation, scanner data must withstand comparison with information available from aerial photography. The familiarity, spatial resolution, and stereoscopic capability of aerial photography can provide much worthwhile information. However, with the analyses and images that can be generated from high-resolution, multispectral data almost any land-cover features can be evaluated. The two techniques should be considered not as competitors but rather as ideal complements that can provide significant insight into restoration of abandoned strip mines.

APPENDIX A

SEPTEMBER LAND-COVER CLASSIFICATION

The locations of the training sites that were used to make the supervised classification of the strip-mined area's land cover are shown in figure 24. The training sites are described in table V, and the statistical and radiometric data are presented in table VI.

In addition to the physical description of the training site, table V includes the number of pixels contained in the training site and their classification accuracy. The classification accuracy is an intermediate result, obtained during the statistical analysis, that indicates the uniformity of the training-site data in describing the class to which the training site was assigned. The classification accuracy of a training site should be high (80 percent) for a general classification of this type. The training-site classification accuracy does not represent the classification accuracy of the entire scene. The descriptions of some training sites include reference to a sample number with pH value, and, for soils, a Munsell color value. These data were obtained during ground surveys of the area.

Table VI presents the mean radiometric value and the standard deviation of each channel for each class. Only channels 4 to 9 were used for this study: Channels 1 and 2 included severe atmospheric haze effects, channel 10 was inoperative, and channel 11 did not contribute significantly to the analyses. These radiometric data were used to establish the spectral signature (i. e., a plot of surface reflectance versus wavelength) of the class and to provide two-channel plots of the radiometric data. These two-channel plots were useful in classifying the data: They are a simple and convenient means of illustrating and interpreting the interactions between the many classes.

The table also includes the first eigenvalue of the covariance matrix. This parameter takes into account all channels being used and is a good measure of the distinctiveness of a specific class. A criterion that was used during the analyses was to limit the classification only to those classes with first eigenvalues greater than 200 in order to insure good class selection. Tight, homogeneous classes such as deep-water ponds have high eigenvalues (1000); nonuniform classes such as revegetated areas have eigenvalues of around 200.

APPENDIX B

SEPTEMBER BARREN-LAND STUDY

The locations of the training sites used for the September barren-land study are shown in figure 25. The training sites are described in table VII, and the statistical and radiometric data are presented in table VIII. There are three points worth mentioning. First, the training sites, especially the barren land areas, were made intentionally small to insure homogeneous and statistically separable areas. Second, the classification accuracy of these training sites is notably low for the barren-land sites, even for the small number of pixels and the high degree of variability in terms of the thematic classification. Third, the high eigenvalues obtained indicate a tight data cluster and pure training-site areas.

APPENDIX C

MARCH BARREN-LAND STUDY

The locations of the training sites used for the March barren-land study are shown in figure 26. The training sites are described in table IX, and the statistical and radiometric data are presented in table X.

Only scanner channels 6 to 10 were used in the final classifications: Preliminary study indicated that the shorter wavelength channels (2 to 5) did not contribute significantly to the final classification. The eigenvalues for only the five channels (6 to 10) are quite large (>200) and indicate the probability of good separability between the classes.

The classification accuracy of the test samples is somewhat low, particularly for the barren-land classes. The accuracy was not improved even by considerable refinement during the analytical procedures to limit the training-site size and to insure proper location of the training site by reviewing the training data in a number of different channels.

APPENDIX D

SEPTEMBER SURFACE-WATER STUDY

The locations of the training sites used for the September surface-water study are shown in figure 27. The training-site description and the pH and radiometric data are presented in table XI. Radiometric data are presented for scanner channels 3 to 11. The radiometric data for the water test sites are tight statistical clusters, as indicated by the small standard deviation and high eigenvalues. For the water areas, the shorter wavelength channels (3 and 4) become important, but the near-infrared channels (8 to 10) are not as useful as they were for the land-cover classes.

APPENDIX E

MARCH SURFACE-WATER STUDY

The locations of the training sites for the March surface-water study are shown in figure 28. The training-site description and the pH and radiometric data are presented in table XII. The March radiometric data are like the September data in that they are tightly clustered, as indicated by the small standard deviation and the high eigenvalues. The March radiometric data range, however, is larger than the September range because of the contribution of the shallow, sediment-laden stream. The 0.6-kilometer altitude at which the March data were obtained was much more suited to the extraction of surface-water data.

APPENDIX F

IMAGE RECTIFICATION PROCEDURE

The multispectral scanner is an airborne line-scanning instrument that views and records a narrow strip (scan line) of the ground scene below the aircraft with a rotating, flat mirror. The data for each scan line are recorded as 803 discrete data points (pixels) that are obtained at a constant sampling rate over 115° of mirror rotation. As the mirror rotates, the location and size of the ground scene imaged by each of the 803 sampling points along a scan line is a function of the "look angle" and is governed by the distance between the scanner mirror and the ground point and by the instantaneous field of view of the optical system. Figure 27 shows the influence of look angle on the pixel location and pixel size in the direction along the scan line. The pixel location and size are proportional to $\tan \theta$ and $\sec^2 \theta$, respectively. Reconstructing a geometrically corrected (rectified) image requires that these variations be accounted for within the limitations of the image recorder system and the hard-copy image product.

For the Optronics image recorder system used, the image is reconstructed point by point and the geometrical corrections are made by repeating pixels in a prescribed manner. The image rectification procedure by data replication that was used to represent the 115° field of view and the 803-pixel scene is shown in table XIII. The approximations involved in this discrete rectification procedure are shown in figure 28. Both the pixel size errors and the pixel location errors that occur are shown. The maximum error in both cases occurs at pixels 123 and 681, or when the transition from 1x to 2x replication occurs. The location error at this point is equivalent to 33 pixels, and the pixel size error is 1.7 times.

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TABLE I. - DATA ACQUISITION FLIGHTS

[Three ground surveys were made of the test site in March and April. The entire 15 km of mined area was surveyed and photographed with 35-mm cameras. Soil and water samples were also obtained for later laboratory analysis. The ground survey was invaluable during interpretation of aerial photographs and the subsequent analysis of scanner data. Flight direction, south to north.]

Flight	Date	Time	Altitude		Comments
			km	ft	
1	September 1974	12:30 p.m.	1.2	4000	Scattered clouds at 1.5 km; slight haze; visibility greater than 8 km; channels 1 and 10 on scanner inoperative
2	March 1975	1:00 p.m.	1.2	4000	High, uniform overcast at 4 km; visibility greater than 20 km; channel 1 inoperative
3	March 1975	10:30 a.m.	.6	2000	Same as for flight 2
4	April 1976	10:00 p.m.	1.2	4000	Night flight; channel 11 thermal data only
5	July 1976	12:30 a.m.	1.2	4000	Same as for flight 4

TABLE II. - SEPTEMBER LAND-COVER STUDY

[Scanner channels, 3 to 9; number of training sites, 34; number of classes, 17; number of colors, 11; rejection level, 9.]

Color	Name	Class	Training site	Area, percent of total area
Dark green	Trees	1	T1	2.29
		2	T2	2.39
		3	T3a, T3b	19.09
Green	Pasture	4	P1	4.16
		5	P2	4.81
		6	P3a, P3b	3.80
Light green	Agriculture	7	Aga, Agb, Agc	5.53
Light yellow	Revegetation I	8	R1	6.69
Dark yellow	Revegetation II	9	R2	20.32
Light blue	Shallow water	10	SWa, SWb, SWc	0.13
Dark blue	Deep water	11	DWa, DWb, DWc, DWd, DWe, DWf	0.32
White	Sandstone bench	12	B1	0.14
		13	B2	.09
	Shale bench	14	B3	1.47
Gray	Shale spoil	16	DSp1a, DSp1b, DSp1c, DSp1d	3.38
Pink	Sandstone spoil	15	Sp1a, Sp1b, Sp1c, Sp1d	8.20
Dark gray	Shadow	17	Sh	0.01
Black	Unclassified	--	-------------	8.7

TABLE III. - SEPTEMBER BARREN-LAND STUDY

[Scanner channels, 4 to 9; number of training sites, 49; number of classes, 27; number of colors, 18; rejection level, 9.]

Color	Name	Class	Training site	Area, percent of total area
Dark green	Trees	18	T1, T2, T3, T4, T5	26.6
Green	Pasture	19	P1, P2, P3, P4, P5, P6, P7, P8	21.2
Light green	Agriculture	20	A1, A2, A3	3.9
Light yellow	Revegetation (50 percent)	21	R1a, R1b	2.75
Dark yellow	Revegetation (90 percent)	22	R2a, R2b, R2c, R2d	20.3
Light blue	Shallow water	23 24 25	W1a, W1b W2 W3	0.10 .02 .02
Dark blue	Deep water	26	DWa, DWb, DWc	0.48
White	Sandstone bench	1	B1a, B1b	0.44
Light gray	Sandstone bench	3	B3	0.11
Gray	Sandstone bench	2	B2	2.12
Dark gray	Sandstone and shale bench	4 15	B4 S1	2.19 .03
Brown	Sandstone and shale bench	5 16	B5 S2	8.40 .07
Pink	Sandstone spoil	6 7	Sp1 Sp2	0.61 2.59
Red	Shale spoil	11	DSp1	0.29
Light purple	Sandstone spoil	8 9 10	Sp3 Sp4 Sp5	0.25 .29 .95
Purple	Shale spoil	12 13 17	DSp2 DSp3 S3	0.08 .23 .23
Dark purple	Shale spoil	14	DSp4	0.11
Very dark gray	Shadow	27	Sha, Shb	1.42
Black	Unclassified	--	-----------------	4.12

TABLE IV. - MARCH BARREN-LAND STUDY

[Scanner channels, 6 to 10; number of training sites, 35; number of classes, 26; number of colors, 20; rejection level, 9.]

Color	Name	Class	Training site	Area, percent of total area
Dark green	Evergreens	16	T1a, T1b	0.55
Green	Hardwoods	17 18	T2a, T1b T3	11.50 18.96
Medium green	Pasture I	19	P1	0.4
Light green	Pasture II	20 21	P2a, P2b, P2c P3a, P3b	7.95 18.23
Light yellow	Revegetation I	22	R1a, R1b	15.90
Dark yellow	Revegetation II	23	R2a, R2b	2.93
Light blue	Shallow water	24 25	W1a, W1b, W1c W2	0.61 .02
Dark blue	Deep water	26	W3	0.01
White	Sandstone bench	1	B1	0.19
Light gray	Sandstone and shale bench	4	B4	2.25
Gray	Sandstone and shale bench	2	B2	4.01
Medium gray	Sandstone and shale bench (wet)	3	B3	0.46
Dark gray	Fly-ash and sewage sludge test area	15	S1	0.39
Pink	Sandstone spoil	5	Sp1	2.60
Red	Sandstone spoil	6 7	Sp2 Sp3	2.15 1.53
Dark red	Sandstone spoil	8	Sp4	6.49
Light purple	Shale spoil	11	DSp1	0.24
Medium purple	Shale spoil	12	CSp2	1.09
Purple	Shale spoil Sandstone spoil	13 10 9	DSp3 Sp6 Sp5	0.23 .61 .46
Dark purple	Shale spoil	14	DSp4	0.35
Black	Unclassified	--	-------------	0.40

TABLE V. - SEPTEMBER LAND-COVER CLASSIFICATION - TRAINING-SITE DESCRIPTION

Name	Class	Training site	Number of pixels in training site	Classification accuracy of training-site pixels	Ground survey or soils map description
Trees	1	T1	234	100	Evergreens
	2	T2	140	84	Black locusts
	3	T3a	325	.73 (24)	Hardwoods - west-facing slope
	3	T3b	558	75 (24)	Hardwoods - north-facing slope
Pasture	4	P1	806	97	Open range - south-facing, moderate slope
	5	P2	754	86	Open range - south-facing, gentle slope
	6	P3a	130	72	Open range - hilltop
	6	P3b	71	86	Open range - east-facing slope
Agriculture	7	Aga	104	100	Hilltop - recently cut
	7	Agb	99	100	Hilltop - recently cut
	7	Agc	173	100	East-facing slope - recently cut
Revegetation	8	R1	74	97	Hilltop - moderately dense vegetation (≈50 percent)
	9	R2	73	93	Hilltop - thick, vigorous vegetation (≈90 percent)
Shallow water	10	SWa	12	100	Shallow impounded water along highwall
	10	SWb	28	100	Shallow impounded water along highwall
	10	SWc	16	100	Shallow impounded water along highwall; pH = 6.7; water sample, 11 - 44
Deep water	11	DWa	24	100	Impounded water along highwall; pH = 3.1; water sample, 11 - 14
	↓	DWb	3	↓	Impounded water along highwall; pH = 3.1; water sample, 11 - 4
		DWc	28		Freshwater hole; pH = 7.1; water sample, 9 - 2
		DWd	30		Freshwater hole; pH = 7.1; water sample, 9 - 2
		DWe	49		Freshwater hole; pH = 7.5; water sample, 9 - 1
		DWf	21		Impounded water along highwall; pH = 7.8; water sample, 9 - 39
Bench	12	B1	54	98	Very yellow-brown sandstone, graded for farming; fine texture; gently sloping; soil sample, 11 - 3; pH = 3.8; Munsell color, 1.5Y 6/4
	13	B2	152	100	Similar to training site B1
	14	B3	154	90	Complex soil color ranging from brown to gray; graded for farming; fine texture; gently sloping; soil sample, 11 - 56; pH = 3.6; Munsell color, 2.5Y 4/2
Sandstone spoil	15	Sp1a	114	97	Dark-gray shale; some grading; moderate slopes; soil sample, 11 - 55; pH = 3.6; Munsell color, 10Yr 3/1
	↓	Sp1b	55	100	Same as training site Sp1a
		Sp1c	118	100	Complex mixture of color and texture ranging from brown to gray and very strong to stony; ungraded steep slope; soil sample, 11 - 51; pH = 3.5
		Sp1d	143	97	Dark gray to olive; ungraded; steep slopes; stony; soil sample, 11 - 54; pH = 3.7; Munsell color, 1.5Y 6/4
Shale spoil	16	DSp1a	182	97	Dark olive-gray; graded; fine loamy texture with moderate slopes; soil sample, 11 - 21; pH = 3.6; Munsell color, 1.5Y 4/2
	16	DSp1b	77	100	Gray; graded; fine texture; complex slopes but generally gently sloping
Shadow	17	Sh	222	100	Highwall shadow

TABLE VI. - SEPTEMBER LAND-COVER CLASSIFICATION - RADIOMETRIC DATA

Name	Class	Scanner channel								First eigen-value of transformed covariance matrix	Channel rank
		3	4	5	6	7	8	9	11		
		Mean radiometric value of sensor data, counts/standard deviation									
Trees	1	40/3	34/3	36/2	30/2	19/2	92/6	174/11	117/4	4 533	6, 9, 7, 8
	2	30/4	28/5	32/3	26/3	16/3	100/17	193/37	116/5	1 970	8, 6, 9, 4
	3	26/5	22/6	29/4	24/4	13/5	75/20	131/37	115/9	915	6, 8, 4, 3
Pasture	4	43/3	45/3	44/2	38/2	27/3	130/5	225/13	144/4	971	6, 8, 9, 7
	5	44/4	43/4	45/3	43/3	33/3	114/7	188/16	147/6	464	6, 7, 5, 3
	6	45/3	45/4	47/2	46/3	35/3	118/6	186/10	146/8	576	6, 9, 4, 8
Agriculture	7	68/5	65/5	67/3	76/4	67/4	130/8	173/13	194/8	292	5, 7, 9, 3
Revegetation I	8	49/3	48/3	50/2	50/3	39/3	109/5	164/13	------	519	9, 7, 8, 5
Revegetation II	9	51/5	51/5	50/5	47/6	35/6	126/8	212/18	------	211	7, 5, 9, 3
Shallow water	10	66/10	65/12	63/15	61/10	41/17	52/11	43/3	90/6	3 294	7, 6, 8, 5
Deep water	11	30/8	25/9	33/7	29/8	15/6	38/4	46/6	92/7	1 443	5, 9, 7, 4
Bench	12	129/6	133/6	135/6	165/8	151/8	168/9	157/9	165/8	3 673	6, 9, 8, 7
	13	149/11	153/11	149/9	180/11	163/11	176/11	163/10	149/8	11 338	9, 6, 7, 8
	14	140/16	131/18	136/16	151/21	136/22	155/23	148/21		1 527	9, 6, 8, 7
Sandstone spoil	15	93/10	89/9	91/8	106/11	93/11	112/10	109/10	229/19	1 012	9, 6, 8, 4
Shale spoil	16	70/6	60/6	65/5	71/7	58/7	77/7	79/8	------	802	8, 9, 4, 5
Shadow	17	39/4	32/4	40/4	38/4	25/5	55/11	67/16	------	295	8, 9, 6, 1

TABLE VII. - SEPTEMBER BARREN-LAND STUDY - TRAINING-SITE DESCRIPTION

Name	Class	Training site	Number of pixels in training site	Classification accuracy of training-site pixels	Ground-survey or soils-map description
Bench	1	B1a	36	45	Light yellow-brown sandstone; graded for farming; fine texture; gently sloping; soil sample, 11 - 3; pH = 3.8; Munsell color, 2.5Y 6/4
	1	B1b	36	90	Similar to training site B1a
	2	B2	48	79	Complex soil color ranging from brown to dark gray; high-sandstone area graded for farming; fine texture; gently sloping, soil sample, 11 - 56; pH = 3.6; Munsell color, 2.5Y 4/2
	3	B3	48	83	Similar to B2 but not a high-sandstone area
	4	B4	48	90	Similar to B2 but a high-shale area
	5	B5	30	100	Gray to dark-gray color; graded for farming; fine-texture, loamy soil suitable for farm machinery; gently sloping; soil sample, 11 - 20; pH = 4.0; Munsell color, 2.5Y 4/2
Sandstone spoil	6	Sp1	78	77	Complex mixture of color and texture ranging from brown to dark gray and stony to very stony; ungraded, steep slope; soil sample, 11 - 51; pH = 3.5
	7	Sp2	78	60	Similar to SP1 but very steep slope
	8	Sp3	48	65	Grayish brown; ungraded moderate slope; soil sample, 11 - 8; pH = 3.3; Munsell color, 2.5Y 5/2
	9	Sp4		79	Yellowish brown sandstone spoil; very stony; ungraded, steep slope; soil sample, 11 - 3; pH = 3.8; Munsell color, 2.5Y 6/4
	10	Sp5		52	Similar to Sp4
Shale spoil	11	Sp5	48	94	Dark gray, graded and ungraded spoil with texture ranging from fine skeletal to stony; moderate to steep slope; soil sample, 11 - 14; pH = 3.5, Munsell color 5Y 4/1
	12	DSp2	48	83	Dark olive-gray; graded; fine loamy texture with moderate slopes; soil sample, 11 - 21; pH = 3.6; Munsell color, 2.5Y 4/2
	13	DSp3	56	86	Dark ungraded spoil with fine texture; steep east-facing slopes
	14	DSp4	56	100	Dark graded spoil with fine texture; moderate west-facing slopes
Test soil	15	S1	63	94	Graded fly-ash soil; dark olive-gray; soil sample, 11 - 45; pH = 5.0
	16	S2	67	90	Graded fly-ash soil; dark olive-gray; somewhat sloping; soil sample, 11 - 49; pH = 5.7
	17	S3	63	62	Graded fly-ash soil; dark gray; sloping; soil sample, 11 - 49; pH = 6.0

TABLE VII. - Concluded.

Name	Class	Training site	Number of pixels in training site	Classification accuracy of training-site pixels	Ground-survey or soils-map description
Trees	18	T1	64	100	Hardwoods; south-facing slope
		T2	64	92	Identical to T1
		T3	56	100	Hardwoods; east-facing slope
		T4	56	93	Identical to T3
		T5	56	70	Hardwoods; west-facing slope
Pasture	19	P1	64	77	Open range; south-facing, moderate slope
		P2	64	95	Identical to P1
		P3	64	95	Open range; south-facing, steep slope
		P4	49	96	Open range; west-facing, gentle slope
		P5	49	96	Open range; east-facing, gentle slope
		P6	49	96	Open range; northeast-facing, gentle slope
		P7	48	98	Open range; west-facing, moderate slope
		P8	88	91	Open range; hilltop
Agriculture	20	A1	48	100	East facing; recently cut
	20	A2	48	100	East facing; recently cut
	20	A3	48	100	East facing; recently cut
Revegetation	21	R1a	116	100	Less than 50-percent fescue
	21	R1b	53	100	Less than 50-percent fescue
	22	R2a	88	100	Fescue; about 90-percent reclamation
	22	R2b	48	62	Fescue; about 90-percent reclamation
	22	R2b	48	62	Fescue; about 90-percent reclamation
	22	R2c	40	97	Approximately 70-percent reclamation
	22	R2d	48	87	Approximately 70-percent reclamation
Water	23	W1a	51	100	Impounded along highwall; shallow
	23	W1b	58	98	Impounded along highwall; shallow; water sample, 11 - 54; pH = 2.8
	24	W2	86	100	Impounded along highwall; deep; water sample, 11 - 14; pH = 3.5
	25	W3	39	100	Impounded along highwall; shallow; water sample, 11 - 14; pH = 3.5
Water	25	DWa	28	96	Deep, freshwater hole; water sample, 9 - 2; pH = 7.1
	26	DWb	24	100	Deep, freshwater hole; water sample, 9 - 1; pH = 7.5
	26	DWc	32	100	Impounded along highwall; deep; water sample, 11 - 44; pH = 6.7
Shadow	27	Sha	13	100	Highwall shadow
	27	Shb	13	100	Highwall shadow

TABLE VIII. - SEPTEMBER BARREN-LAND STUDY - RADIOMETRIC DATA

Name	Class	Scanner channel							First eigen-value of transformed covariance matrix	Channel rank
		3	4	5	6	7	8	9		
		Mean radiometric value of sensor data, counts/standard deviation								
Bench	1	141/15	145/15	143/12	173/14	157/13	172/12	160/10	406	7, 6, 4, 9
	2	128/8	128/9	126/8	152/10	139/10	159/9	153/8	662	7, 4, 3, 8
	3	144/14	130/14	123/13	147/17	131/17	149/17	142/16	3781	6, 9, 4, 7
	4	100/11	92/12	93/11	109/14	95/15	114/15	111/14	2174	6, 9, 8, 3
	5	97/9	89/9	89/8	102/11	88/10	115/7	120/5	143	7, 8, 9, 4
Sandstone spoil	6	88/7	86/7	91/7	107/9	94/9	111/9	107/8	2248	6, 9, 7, 4
	7	92/9	88/9	91/8	107/10	93/10	113/11	112/10	1062	7, 6, 9, 4
	8	84/6	83/7	88/6	103/6	91/8	111/8	108/8	1111	7, 9, 6, 4
	9	83/7	84/7	90/7	106/8	93/8	112/8	109/7	2131	6, 9, 7, 3
	10	82/8	80/8	86/7	100/9	87/10	107/9	106/9	835	9, 7, 6, 3
Shale spoil	11	93/7	81/6	82/5	93/7	78/7	93/7	89/6	2670	6, 7, 9, 8
	12	70/5	61/5	65/4	72/6	59/6	77/6	77/5	4451	9, 6, 7, 4
	13	68/4	56/4	60/3	65/4	52/4	71/4	73/4	1970	9, 6, 7, 8
	14	57/4	45/4	50/3	51/4	38/4	58/4	63/3	2229	9, 6, 7, 3
Test soil	15	104/12	92/11	93/9	111/12	98/12	115/12	112/11	2144	6, 7, 9, 4
	16	84/5	70/4	71/3	78/4	63/5	82/4	80/3	2044	3, 9, 6, 5
	17	68/5	57/4	62/3	67/4	54/4	72/4	72/3	1768	9, 7, 5, 3
Trees	18	30/13	27/6	32/4	17/5	17/5	89/19	159/36	524	8, 6, 9, 5
Pasture	19	45/4	46/5	44/3	40/3	29/4	131/14	226/30	398	8, 9, 6, 7
Agriculture	20	69/4	68/4	68/3	76/4	67/4	136/5	186/6	763	6, 8, 7, 5
Revegetation	21	61/3	57/3	61/3	68/4	59/4	109/5	141/7	470	7, 5, 9, 6
	22	51/4	51/5	51/4	49/5	38/5	117/16	184/37	281	9, 4, 8, 6
Water	23	71/14	70/4	72/4	74/5	52/5	63/10	47/9	592	8, 9, 7, 6
	24	52/3	48/3	42/2	32/2	16/2	37/2	44/1	9667	8, 5, 9, 7
	25	39/3	43/4	52/4	50/6	30/5	40/3	36/1	9082	8, 7, 5, 6
	26	29/5	24/6	32/5	28/5	14/4	37/4	44/8	794	7, 3, 5, 4
Shadow	27	40/4	32/4	40/3	37/4	25/5	52/7	62/9	386	8, 9, 4, 5

TABLE IX. - MARCH BARREN-LAND STUDY - TRAINING-SITE DESCRIPTION

Name	Class	Training site	Number of pixels in training site	Classification accuracy of training-site pixels	Ground-survey or soils-map description
Bench	1	B1	165	96	Light yellow-brown sandy soil; graded for farming; fine texture; gently sloping; soil sample, 11 - 3; pH = 3.8; Munsell color, 1.5Y 6/4
	2	B2	57	93	Complex soil color ranging from gray to very dark-gray shale; graded for farming; fine texture; gently sloping; soil sample, 11 - 0; pH = 1.8; Munsell color, 5Y 2.5/1
	3	B3	24	58	Complex soil color ranging from brown to dark gray; graded for farming; fine texture; gently sloping; soil sample, 11 - 56; pH = 3.6; Munsell color, 1.5Y 4/2
	4	B4	50	92	Gray to dark-gray color; graded for farming; fine-texture, loamy soil suitable for farm machinery; gently sloping; soil sample, 11 - 20; pH = 4.0; Munsell color, 2.5Y 4/2
Spoil	5	Sp1	21	57	Complex mixture of color and texture ranging from brown to dark gray and stony to very stony; ungraded, steep slope; soil sample, 11 - 51; pH = 3.5
	6	Sp2	123	64	Yellowish brown spoil; very stony; ungraded, steep slope; soil sample, 11 - 3; pH = 3.8; Munsell color, 2.5Y 6/4
	7	Sp3	44	66	Similar to Sp2
	8	Sp4	63	79	Brown sandstone spoil; very stony; steep slope
	9	Sp5	30	70	Similar to Sp4 but lighter brown color
	10	Sp6	40	57	Similar to Sp1 but slide area with possible fly-ash surface
Dark spoil	11	DSp1	28	89	Gray, graded, fine-texture spoil; complex gentle slopes
	12	DSp2	24	75	Dark olive, graded and ungraded spoil with texture ranging from fine skeletal to stony; moderate to steep slope; soil sample, 11 - 14; pH = 3.5; Munsell color, 5Y 4/1
	13	DSp3	33	61	Dark, ungraded spoil with fine texture and steep east-facing slopes
	14	DSp4	60	92	Dark, graded spoil with fine texture and moderate, west-facing slopes

TABLE IX. - Concluded.

Name	Class	Training site	Number of pixels in training site	Classification accuracy of training-site pixels	Ground-survey or soils-map description
Test soil	15	S1	48	48	Graded fly-ash soil; dark olive-gray; soil sample, 11 - 45; pH = 5.0; Munsell color, 5Y 2.5/2
Evergreens	16	T1a	54	100	Evergreens
	16	Tb1	54	100	Evergreens
Black locusts	17	T2a	100	99	Black locusts; no foliage
	17	T2b	56	100	Black locusts; no foliage
Hardwoods	18	T3		89	Hardwoods; no foliage
Pasture	19	P1	40	100	Open range; southeast-facing, gentle slope; somewhat worn
	20	P2a		97	Open range; south-facing, moderate slope
	20	P2b		100	Open range; south-facing, moderate slope
	20	P2c		95	Open range; south-facing, moderate slope
	21	P3a	108	95	Open range; southeast-facing, moderate slope
	21	P3b	108	90	Open range; hilltop
Revegetation	22	R1a	43	98	Less than 50-percent reclamation (straw-colored, dormant)
	22	R1b	78	94	Less than 50-percent reclamation (straw-colored, dormant)
	23	R2a	68	88	Thick; almost 100-percent reclamation (straw-colored, dormant)
	23	R2b	68	76	Thick; almost 100-percent reclamation (straw-colored, dormant)
Water	24	W1a	99	100	Deep, freshwater hole; water sample, 9 - 2; pH = 7.1
	24	W1b	108	97	Deep, freshwater hole; water sample, 9 - 1; pH = 7.5
	24	W1c	87	100	Impounded water by highwall; deep; water sample, 9 - 44; pH = 6.7
	25	W2	23	100	Deep impounded water
	26	W3	25	100	Deep impounded water by highwall; water sample, 11 - 14; pH = 6.7

TABLE X. - MARCH BARREN-LAND STUDY - RADIOMETRIC DATA

Name	Class	Scanner channel								First eigen-value of transformed covariance matrix	Channel rank
		3	4	5	6	7	8	9	10		
		Mean radiometric value of sensor data, counts/standard deviation									
Bench	1	185/8	221/8	235/8	211/7	195/7	189/6	184/6	147/6	2 418	9, 7, 6, 8
	2	132/13	147/17	167/19	157/18	150/18	155/10	162/22	138/21	292	7, 9, 8, 10
	3	137/6	134/8	134/8	119/7	108/7	103/7	102/7	83/6	3 850	7, 9, 8, 10
	4	168/9	180/10	190/11	180/11	174/11	188/10	210/10	195/9	1 022	9, 7, 6, 8
Sandstone spoil	5	163/15	185/17	195/19	176/16	164/15	161/15	159/14	129/12	723	8, 6, 7, 9
	6	142/10	167/15	182/18	165/16	154/15	152/15	150/14	122/11	1 674	7, 9, 8, 6
	7	134/5	157/7	171/7	155/6	144/6	145/6	144/6	117/6	639	8, 9, 7, 6
	8	137/6	149/8	157/9	142/8	131/8	130/8	132/8	111/7	559	7, 9, 8, 10
	9	128/5	131/5	133/6	118/5	109/5	105/5	105/5	84/4	5 823	7, 9, 8, 6
	10	119/5	125/6	129/6	115/6	106/6	103/6	103/5	83/5	3 015	9, 6, 7, 10
Shale spoil	11	142/6	146/7	147/6	130/6	119/5	113/5	110/4	87/4	2 553	9, 6, 8, 7
	12	127/3	133/4	136/4	123/4	113/3	110/3	110/3	90/3	8 924	9, 7, 6, 10
	13	130/4	128/4	130/4	116/3	105/3	101/3		81/3	3 209	7, 9, 8, 6
	14	124/3	120/3	120/3	107/3	97/3	93/3	93/3	76/3	3 858	9, 7, 6,8
Test soil	15	106/4	106/5	109/6	98/5	89/5	89/5	90/5	72/4	1 905	6, 9, 8, 7
Trees	16	73/3	79/5	73/4	61/3	56/3	119/13	190/26	160/18	1 103	9, 10, 8, 6
	17	101/4	105/5	109/5	101/5	98/5	130/7	168/11	159/6	330	6, 10, 7, 9
	18	------	------	------	109/7	108/8	124/9	153/12	154/12	391	6, 10, 9, 7
Pasture	19	------	------	114/3	98/4	90/3	173/4	154/3	235/9	3 657	9, 8, 6, 7
	20	------	------	156/9	143/10	136/10	187/5	146/8	131/8	493	7, 6, 10, 8
	21	------	------	191/14	179/14	173/14	201/13	135/15	217/14	139	6, 7, 10, 8
Revegetation	22	------	------	175/17	162/16	155/16	178/17	204/18	187/15	116	10, 7, 6, 8
	23	------	------	213/19	201/18	193/18	205/19	224/19	205/16	180	7, 9, 8, 10
Water	24	------	------	149/23	119/14	96/10	77/7	65/4	48/4	1 759	9, 6, 8, 7
	25	------	------	111/2	95/1	81/1	69/1	61/1	45/2	21 670	9, 8, 7, 10
	26	------	------	108/1	83/1	66/1	56/1	54/1	41/1	19 569	9, 10, 8, 6

TABLE XI. - SEPTEMBER SURFACE-WATER STUDY - RADIOMETRIC DATA

[Aircraft altitude, 1.2 km.]

Name	Class	pH level	Scanner channel								First eigen-value of transformed covariance matrix	Channel rank
			3	4	5	6	7	8	9	11		
			Mean radiometric value of sensor data, counts/standard deviation									
Shallow impoundment	1	---	73/3	74/4	80/3	89/3	68/3	70/2	53/2	83/4	5 262	3, 7, 8, 9
Very shallow impoundment	2	2.6	72/4	71/3	69/2	69/2	47/3	52/2	40/1	89/2	16 751	4, 3, 7, 5
Impoundment - pale green	3	---	71/3	69/4	67/3	66/3	44/3	54/2	52/3	83/3	1 808	6, 4, 3, 11
Valley pond - yellow	4	3.9	67/4	84/5	89/5	97/5	73/5	70/2	48/2	88/5	2 478	5, 9, 3, 6
Impounded pit - black	5	---	66/3	59/3	50/2	42/2	25/2	43/2	47/1	75/3	4 473	7, 9, 8, 5
Shallow impoundment - red, brown, and yellow	6	2.8	64/5	65/4	69/3	73/4	53/4	65/5	50/4	100/3	4 351	5, 3, 11, 9
Valley pond - green	7	7.2	62/3	63/4	62/3	57/4	35/4	44/3	40/1	77/3	4 396	7, 9, 8, 6
Impoundment - green	8	6.7	54/3	50/3	43/3	33/3	17/3	39/2	47/1	87/2	2 851	4, 7, 11, 9
Impoundment - green	9	6.7	52/2	48/3	42/2	32/1	17/2	37/2	44/1	84/2	5 653	7, 8, 9, 11
Shallow impoundment	10	---	50/3	47/3	52/2	49/2	32/2	47/2	47/1	89/2	14 334	3, 5, 4, 8
Impoundment - light green	11	7.8	48/3	45/3	49/2	46/2	29/2	45/2	45/1	84/3	14 957	5, 3, 8, 4
Impoundment - light green	12	7.8	44/2	39/2	44/2	41/1	25/2	41/1	43/2	88/4	4 374	3, 8, 6, 4
Farm pond - pale green	13	7.0	44/3	40/2	45/2	42/2	27/2	48/2	55/1	98/2	15 372	4, 8, 9, 7
Deep impoundment	14	---	42/3	33/3	40/2	37/3	23/3	45/3	50/4	91/5	2 303	7, 5, 9, 4
Deep impoundment - black	15	7.8	43/3	34/3	40/2	37/1	23/2	39/2	38/1	95/3	4 342	9, 8, 7, 5
Shallow impoundment - yellow brown	16	3.1	39/3	43/4	51/4	50/4	29/4	39/3	36/1	88/3	3 219	8, 5, 9, 4
Impoundment - pale green	17	3.1	34/3	30/3	38/2	33/2	17/2	32/1	34/1	85/2	5 396	4, 11, 9, 6
Farm pond - dark green	18	---	37/2	32/2	38/1	34/1	20/1	46/2	54/1	91/2	10 688	6, 3, 9, 4
Farm pond - dark green	19	---	34/2	25/2	32/1	27/1	13/2	37/2	45/1	95/3	2 923	9, 3, 6, 8
Farm pond	20	---	29/3	23/3	32/2	28/2	15/2	42/2	52/1	99/3	2 647	9, 8, 11, 4
Valley pond - light-green vegetation	21	7.3	28/4	21/4	30/3	25/4	12/3	32/3	37/2	78/4	1 450	7, 4, 8, 9
Valley pond - dark-green vegetation	22	7.1	26/3	19/3	29/2	24/3	12/3	35/3	44/4	90/5	899	9, 6, 8, 3
Deep impoundment - dark green	23	---	25/2	16/2	25/2	20/1	8/2	25/2	30/1	84/2	5 042	3, 11, 8, 4
Farm pond - dark green	24	---	23/3	17/2	26/2	21/2	9/2	35/2	47/1	90/2	9 937	9, 6, 3, 11
Shadow	27	---	41/4	34/3	42/2	41/1	28/2	51/2	56/3	67/4	1 164	3, 5, 7, 11
Shadow	28	---	43/3	37/2	45/2	44/3	31/3	52/3	57/4	66/5	562	8, 11, 4, 7
Barren land	31	---	97/6	85/6	86/5	98/6	84/6	106/5	107/6	243/13	484	7, 5, 3, 4
Barren land	32	---	87/9	87/10	93/9	110/13	96/13	115/13	110/15	152/12	117	4, 8, 7, 6
Barren land	33	---	89/23	76/8	79/8	90/11	76/10	96/8	97/11	227/18	316	7, 5, 6, 11
Wetland	34	---	65/4	60/4	65/3	76/4	67/5	117/5	146/6	251/5	8 474	5, 7, 3, 4
Pasture	36	---	45/4	47/4	46/2	40/2	29/2	131/4	221/10	144/4	1 520	8, 3, 11, 4
Hardwoods	37	---	28/4	25/6	31/4	25/4	15/4	81/19	145/34	119/8	431	6, 8, 4, 3
Hardwoods	38	---	24/4	19/5	27/4	21/4	10/4	56/17	96/30	102/13	431	8, 6, 9, 5

TABLE XII. - MARCH SURFACE-WATER STUDY - RADIOMETRIC DATA

[Aircraft altitude, 0.6 km.]

Name	Class	pH level	Scanner channel									First eigen-value of transformed covariance matrix	Channel rank
			3	4	5	6	7	8	9	10	11		
			Mean radiometric value of sensor data, counts/standard deviation										
Sediment-loaded stream	1	5.6	172/5	201/8	206/9	177/7	153/5	119/3	84/2	47/4	91/1	1 720	4, 6, 5, 8
	2	5.6	171/3	200/4	207/5	177/4	152/3	118/2	84/1	44/3	95/2	3 721	4, 6, 9, 11
	3	5.6	164/6	187/6	192/6	164/5	144/4	115/2	86/2	49/2	95/1	2 830	4, 3, 7, 6
	4	4.9	146/6	162/7	167/7	145/6	129/4	110/1	90/2	48/4	95/1	1 074	5, 4, 7, 9
Impoundment - green	5	6.7	143/3	173/3	160/2	118/2	90/2	68/2	56/2	39/3	133/1	5 769	9, 8, 5, 3
Shallow impoundment - gray	6	7.1	128/5	140/6	143/5	125/3	112/3	98/7	81/10	46/5	69/2	857	8, 5, 3, 11
Very shallow impoundment - yellow-brown	7	4.0	119/3	141/3	148/3	124/2	102/2	76/2	55/2	38/4	87/8	1 991	9, 5, 3, 6
Drainage stream	8	---	108/3	117/3	117/3	99/2	84/2	72/2	63/2	47/4	123/2	2 055	9, 3, 8, 5
Shallow impoundment - light brown	9	3.8	107/3	124/4	136/6	118/7	100/8	86/8	64/7	37/4	94/3	1 279	9, 5, 7, 4
Shallow impoundment - yellow-brown	10	2.9	103/4	118/4	122/4	102/5	83/4	69/4	54/2	38/3	69/1	4 983	5, 4, 11, 7
Shallow impoundment - pale green	11	3.8	100/3	111/4	110/3	88/2	71/1	58/2	50/2	38/3	95/2	2 833	3, 9, 10, 11
Shallow impoundment - pale green	12	6.4	90/3	102/4	97/3	77/3	62/2	53/2	50/1	40/4	86/2	1 898	9, 6, 5, 3
Shallow impoundment - yellow-brown	13	3.1	97/4	125/7	121/9	93/8	71/6	56/4	49/2	35/4	118/1	1 733	6, 9, 8, 4
Impoundment - pale green	14	3.1	90/2	100/2	93/2	73/2	58/2	49/2	48/2	35/4	123/2	2 562	9, 8, 3, 4
Shallow impoundment - light blue-green	15	3.2	80/2	91/3	92/3	75/2	60/2	51/1	49/1	37/3	115/2	3 122	9, 3, 8, 11
Shallow impoundment - dark red-brown	16	2.8	78/3	85/4	97/5	88/5	74/4	72/4	59/2	44/3	86/4	2 104	4, 9, 6, 5
Shallow impoundment - light blue-green	17	3.2	77/2	82/3	85/2	71/2	60/2	49/1	49/1	39/3	118/3	4 689	3, 8, 9, 11
Drainage stream	18	4.4	75/5	76/6	82/5	75/5	72/3	81/4	98/2	94/2	87/3	34 306	3, 9, 4, 6
Shallow impoundment - dark brown	19	---	65/4	70/7	81/9	78/8	65/8	55/6	50/3	40/5	73/2	3 642	4, 8, 7, 9

TABLE XIII. - IMAGE RECTIFICATION PROCEDURE

BY DATA REPLICATION

Scanner pixel	Number of pixels	Pixel replications	Number of image points
1 - 7	7	4x	28
8 - 71	64	3x	192
72 - 122	51	2x	102
123 - 401	279	1x	279
402 (nadir)	1	1x	1
403 - 681	279	1x	279
682 - 732	51	2x	102
733 - 796	64	3x	192
797 - 803	7	4x	28
Total	803	--	1203

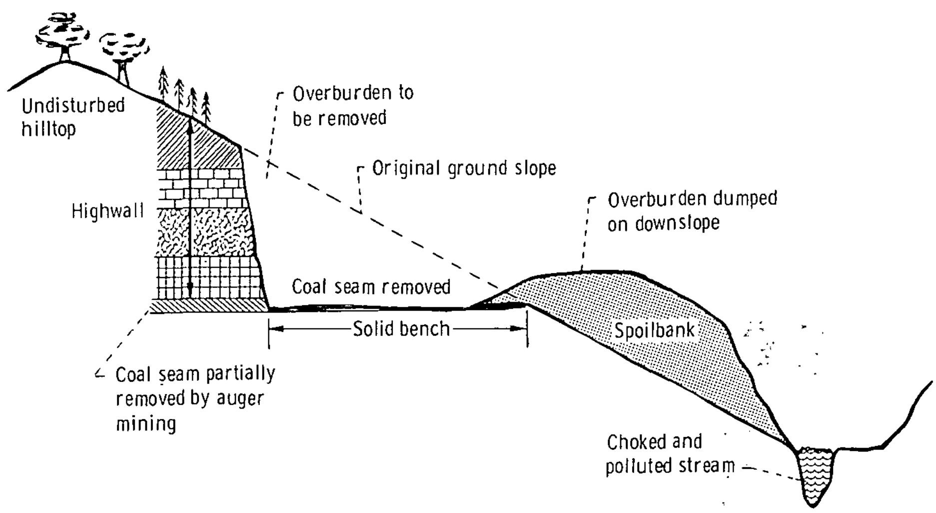
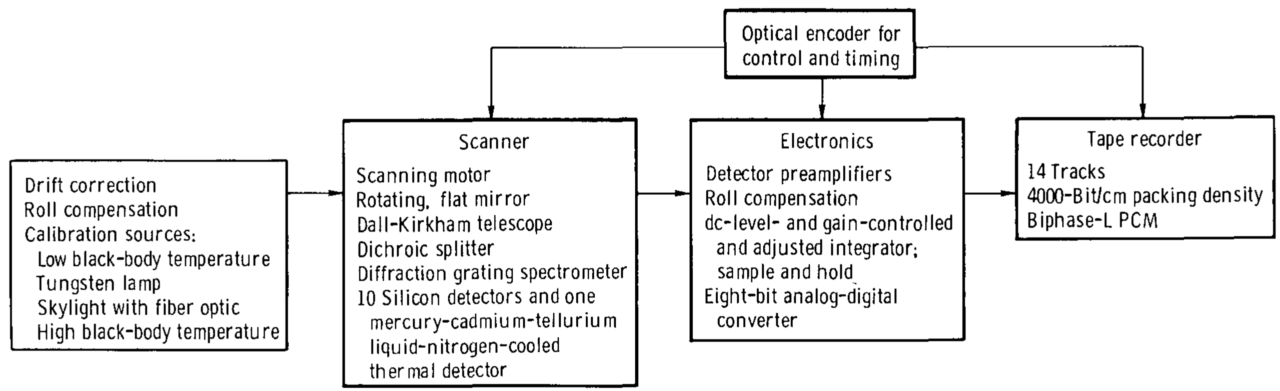
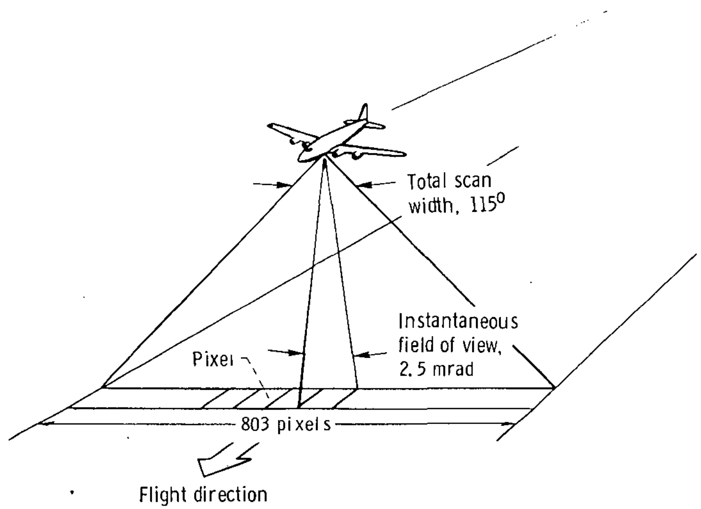


Figure 1. - Conventional contour mining.

Figure 2. - Aerial photograph of EORDC strip-mine test site. Scale, 24 000.



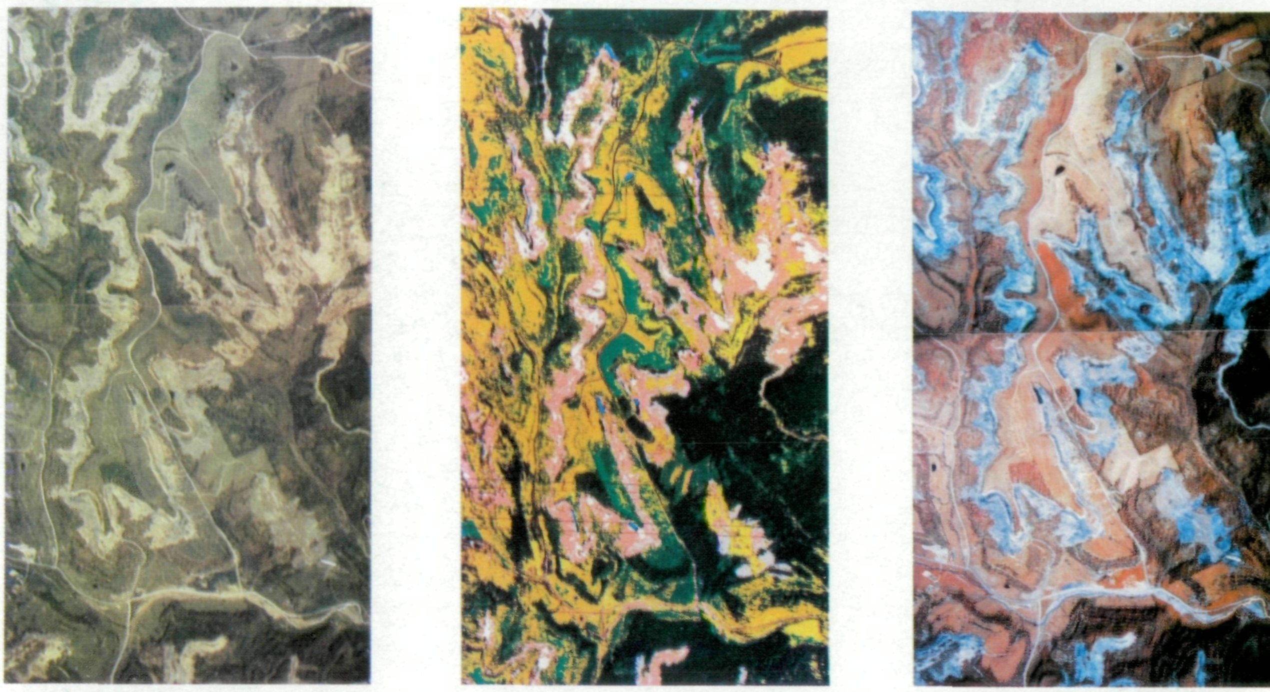


Spectrum	Channel	Center wavelength, µm	Band width, µm	Detector
Visible	1	0.41	0.06	Silicon
	2	.465	.05	
	3	.515	.05	
	4	.560	.04	
	5	.600		
	6	.640		
	7	.680		
Near infrared	8	0.720	0.04	Silicon
	9	.815	.09	Silicon
	10	1.015	.09	Silicon
Thermal	11	11.0	6.0	Hg-Cd-Te

Figure 3. - Characteristics of multispectral scanner.

Figure 4. - Multispectral scanner image. May 1976; channel 7; altitude, 1.2 kilometers.

Figure 5. - Typical training site. (Cursor superimposed over final color classification.)



(a-1) Natural-color aerial photograph.

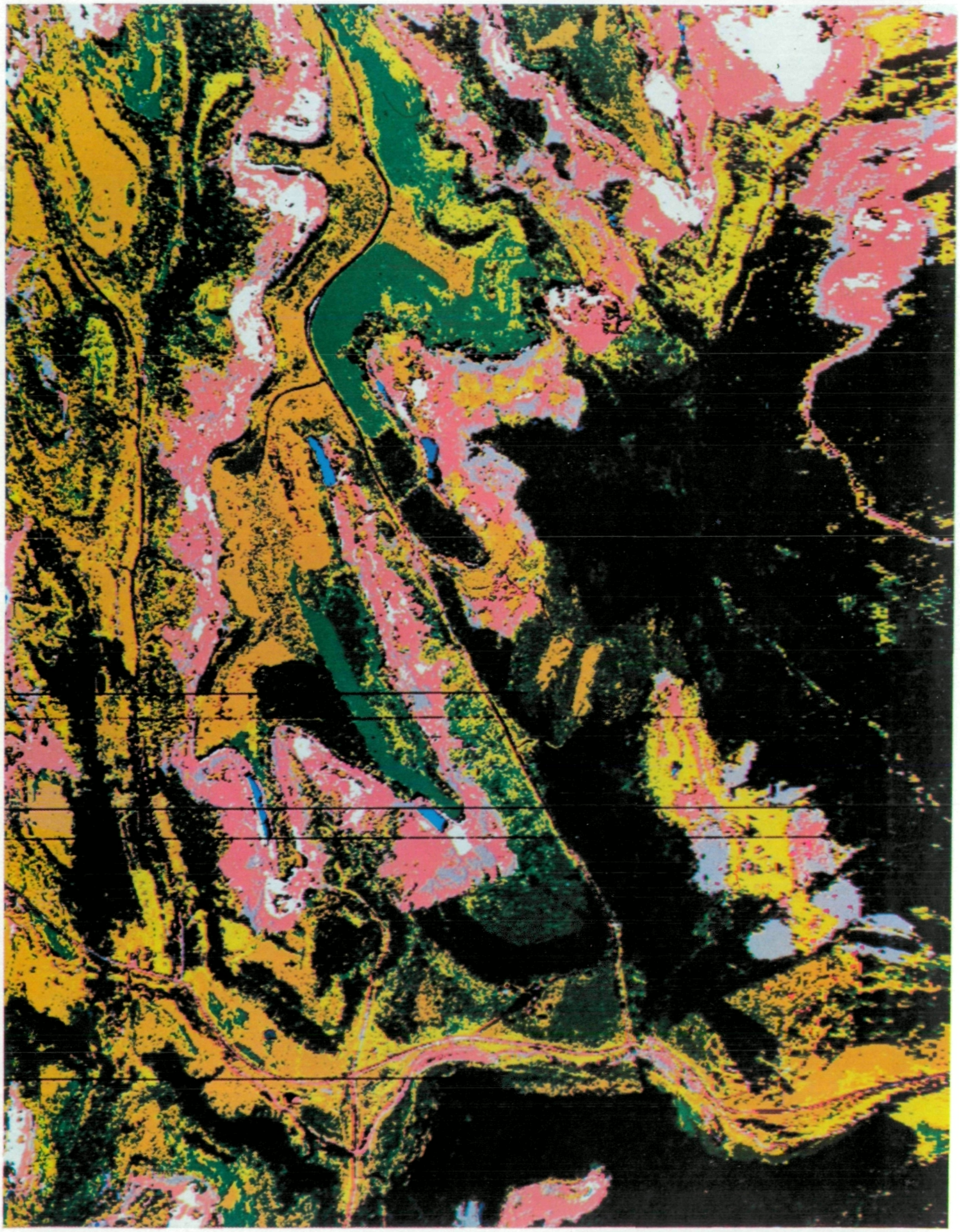
(a-2) Computer-classified color image.

(a-3) Color infrared aerial photograph.

Forest
Pasture
Agriculture
Revegetation (≈50 percent)
Revegetation (≈90 percent)
Shallow water
Deep water
Sandstone bench
Shale spoil
Sandstone and shale spoil
Shadow

(a) Comparison of computer-classified color image and aerial photographs. Scale factor, 36 000.

Figure 6. - Computer-classified color image and aerial photographs of test site - September land-cover classification.



(b) Enlargement of computer-classified color image of southern section of test site (fig. 6(a-2)). Scale factor, 12 000.

Figure 6. - Concluded.

Figure 7. - Aerial photograph of southern section of test site (fig. 6(a)). Scale factor, 12 000.

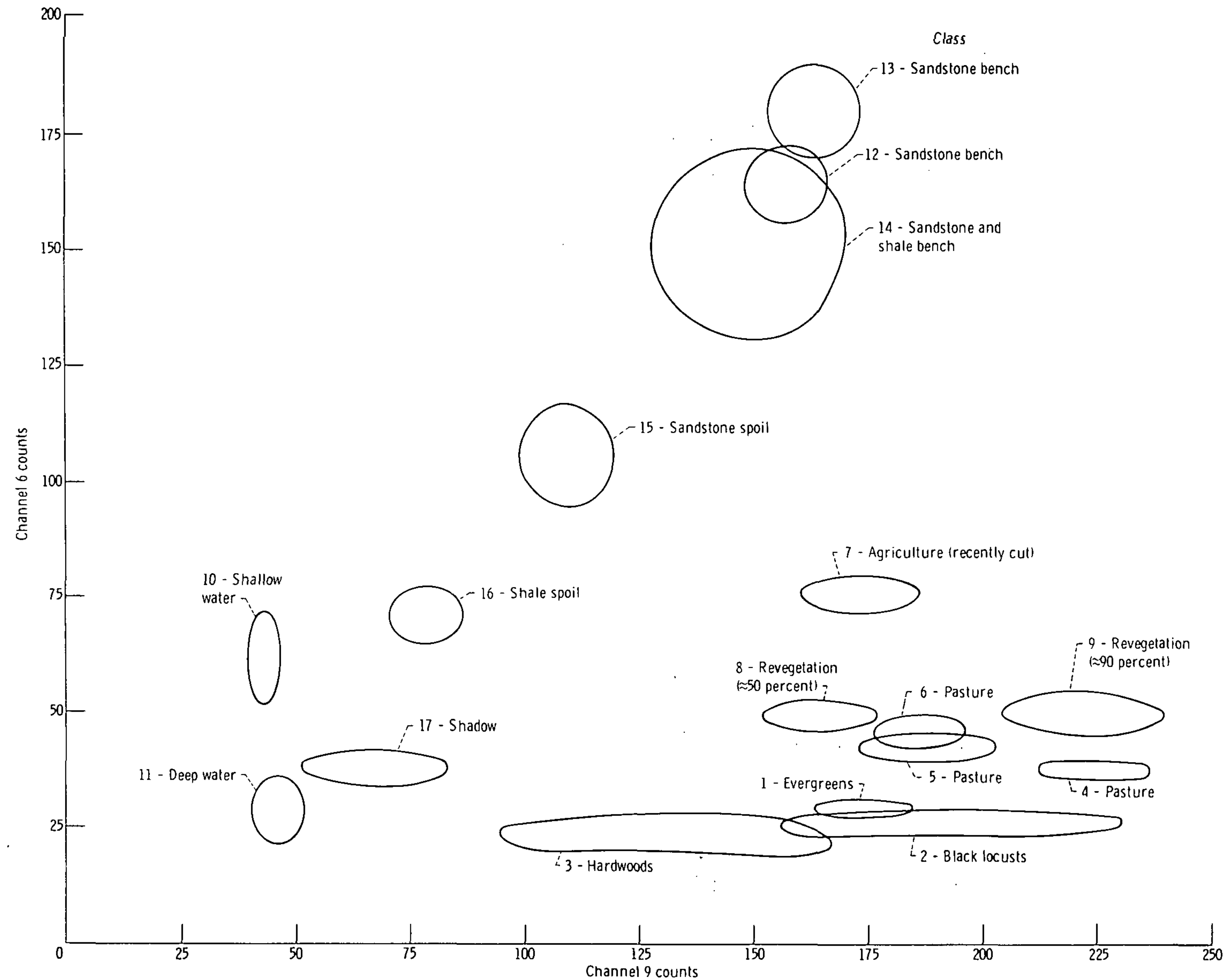
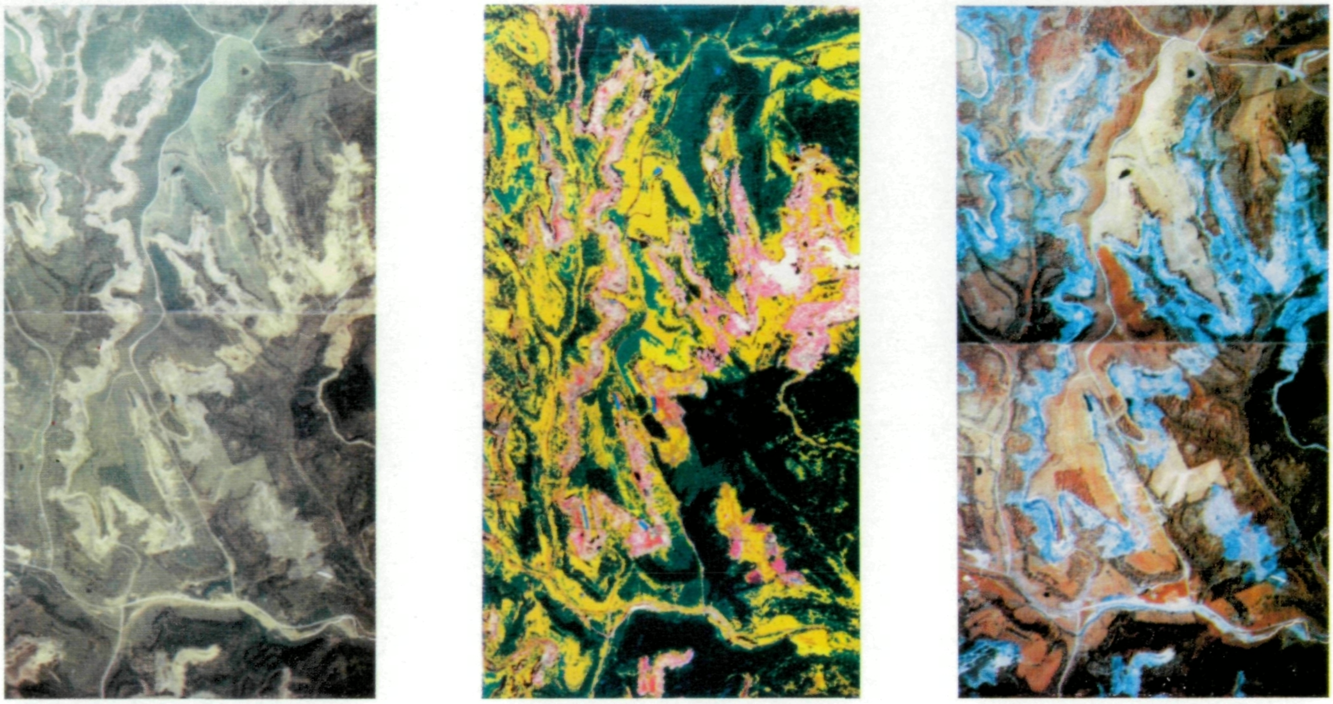


Figure 8. - Sensor data for channels 6 and 9 - September land-cover classification.



(a-1) Natural-color aerial photograph.

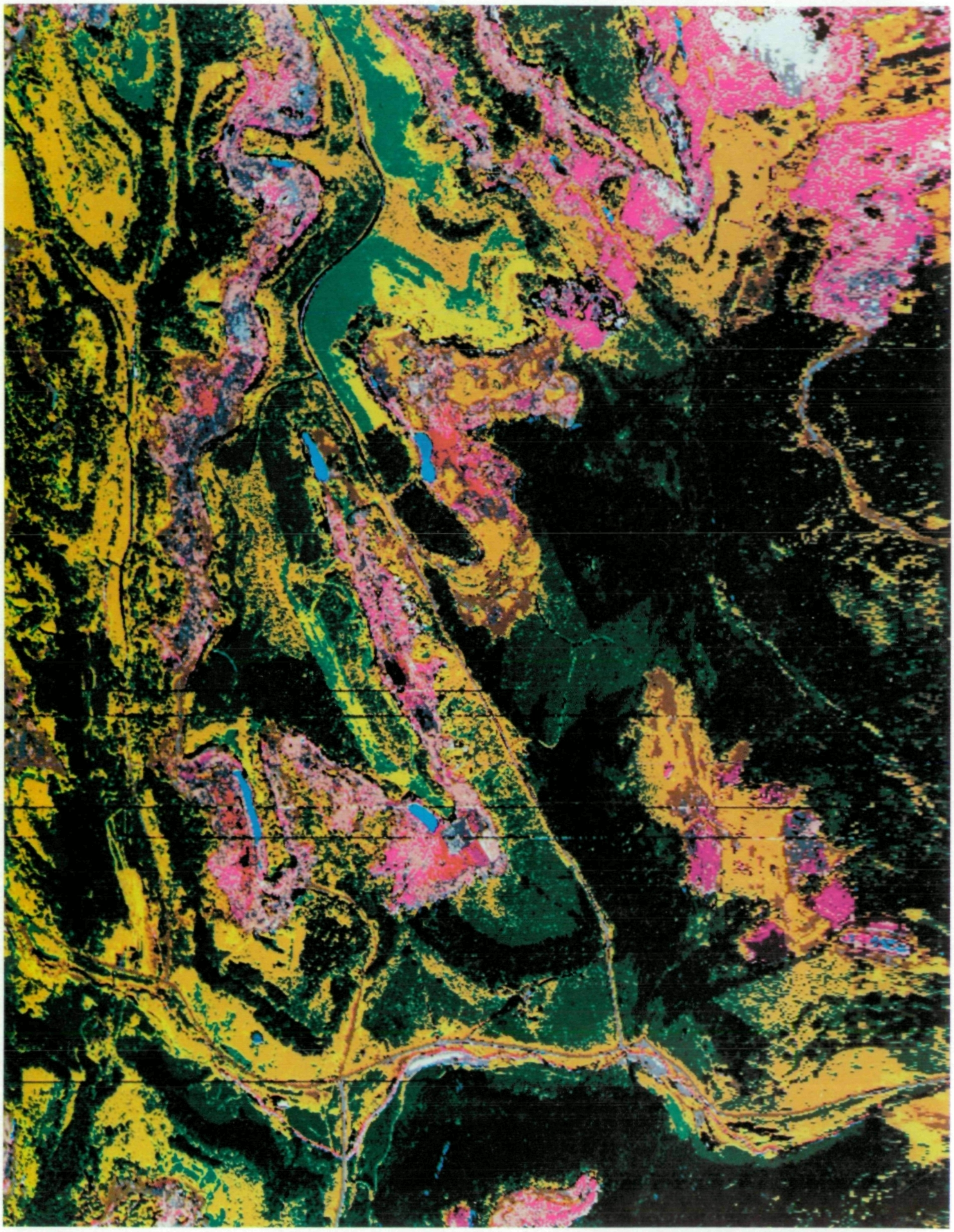
(a-2) Computer-classified color image.

(a-3) Color infrared aerial photograph.

Forest
Pasture
Agriculture
Revegetation (< 50 percent)
Revegetation (> 50 percent)
Shallow water
Deep water
Sandstone bench
Sandstone and shale bench
Sandstone spoil
Shale spoil
Sandstone spoil
Shale spoil
Shadow

(a) Comparison of computer-classified color image and aerial photographs. Scale factor, 36 000.

Figure 9. - Computer-classified color image and aerial photographs of test site - September barren-land study.



(b) Enlargement of computer-classified color image of southern section of test site (fig. 9(a-2)). Scale factor, 12 000.

Figure 9. - Concluded.

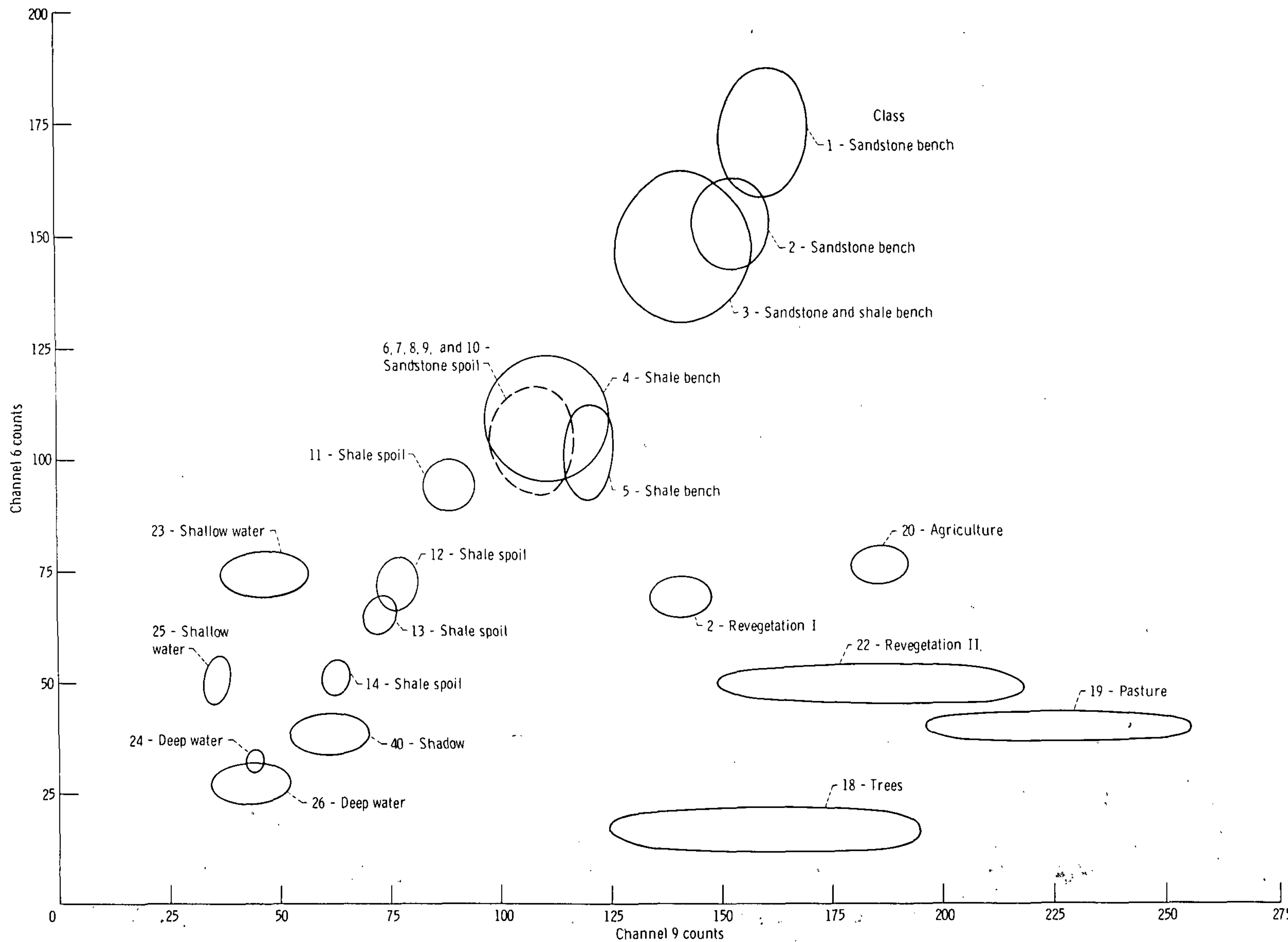
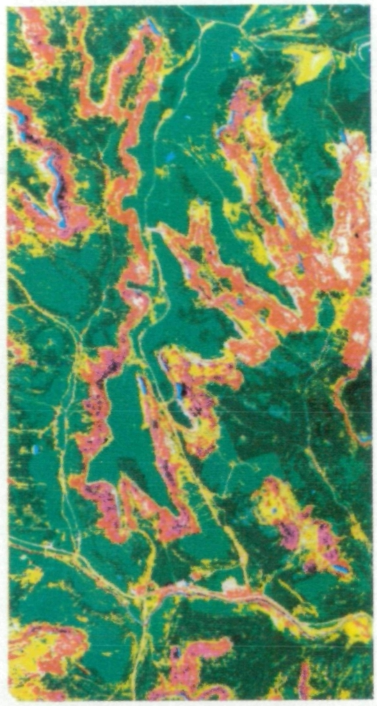


Figure 10. - Sensor data for channels 6 and 9 - September barren-land study.

(a-1) Natural-color aerial photograph.

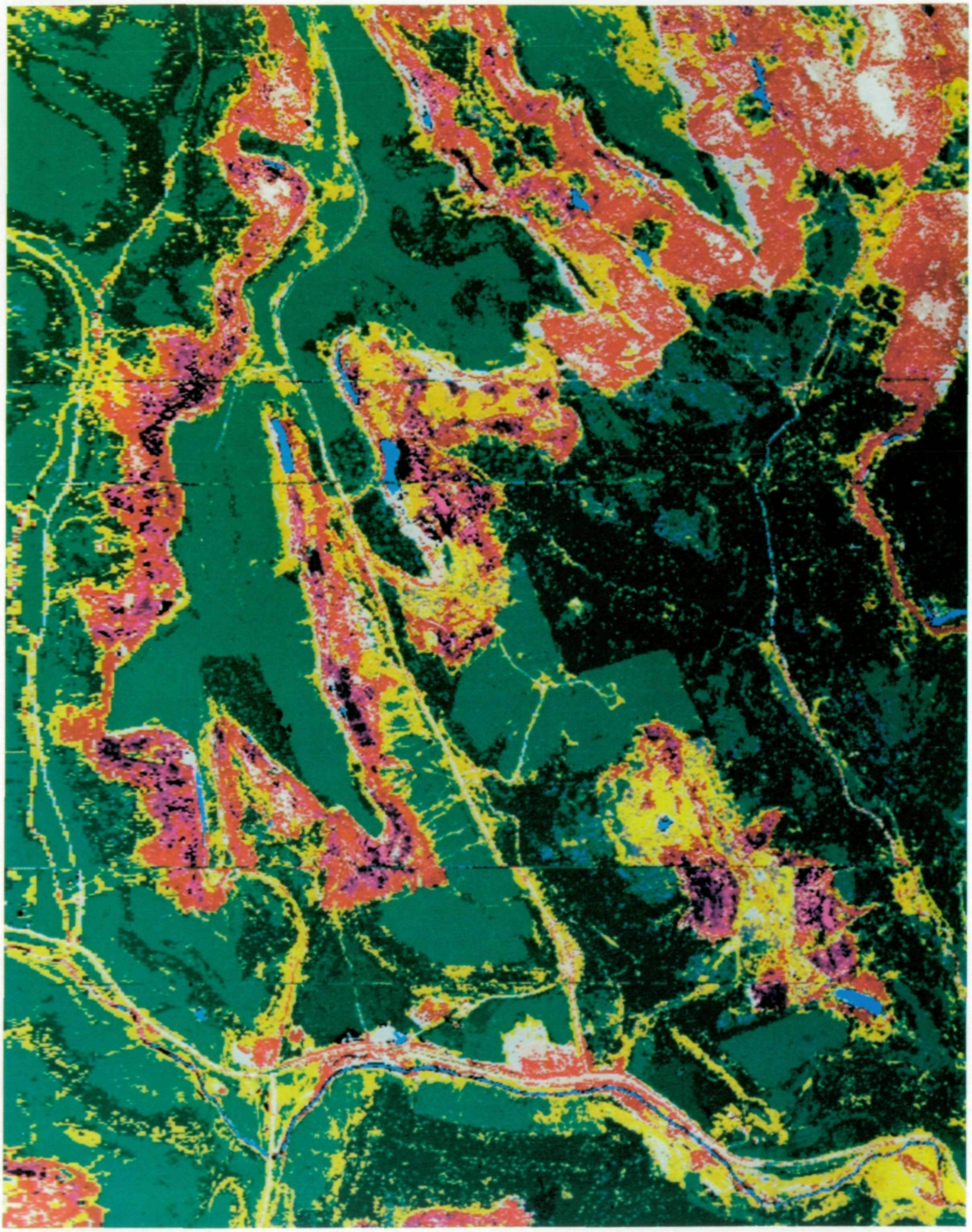


(a-2) Computer-classified color image.

(a-3) Color infrared aerial photograph.

(a) Comparison of computer-classified color image and aerial photographs.

Figure 11. - Computer-classified color image and aerial photographs of test site - March barren-land study.



(b) Enlargement of computer-classified color image of southern section of test site (fig. 11(a-2)). Scale factor, 12 000.

Figure 11. Concluded.

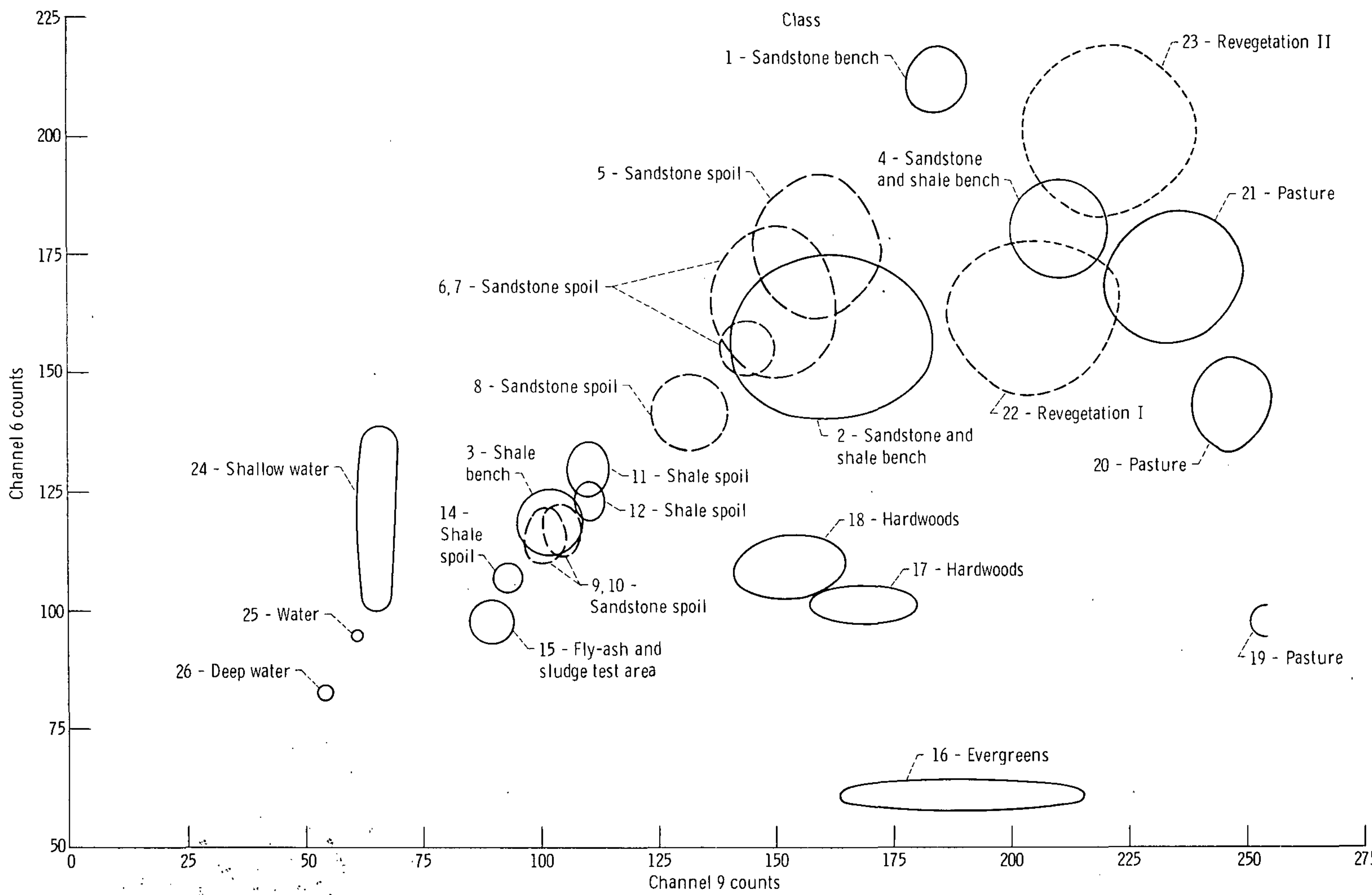
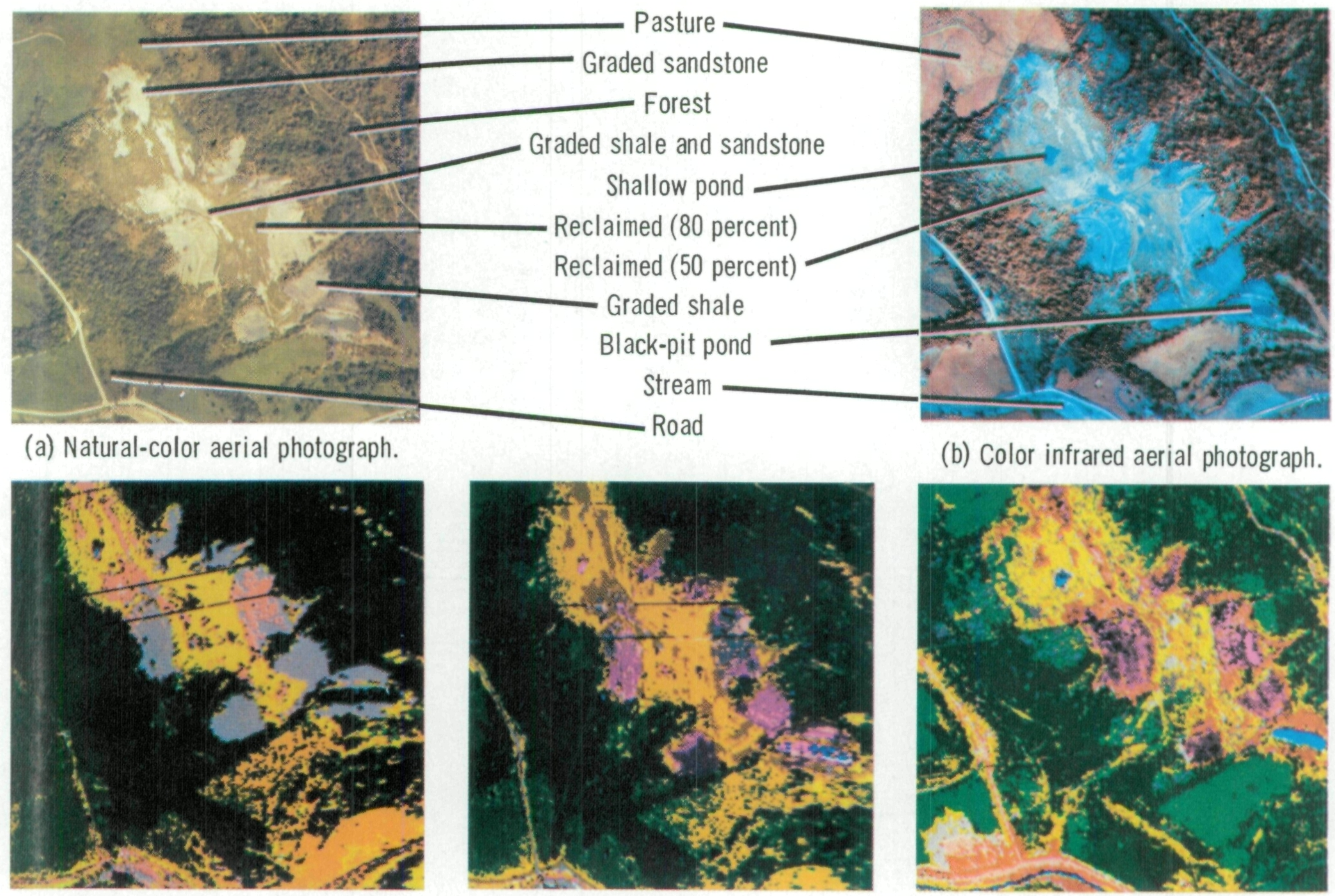


Figure 12. - Sensor data for channels 6 and 9 - March barren-land study.

Figure 13. - Location of subareas in southern section of test site. Scale factor, 12 000.



(a) Natural-color aerial photograph.

(b) Color infrared aerial photograph.

(c) September classification land-cover.

(d) September barren-land study.

(e) March barren-land study.

Figure 14. - Subarea 1. Scale factor, approximately 18 000.

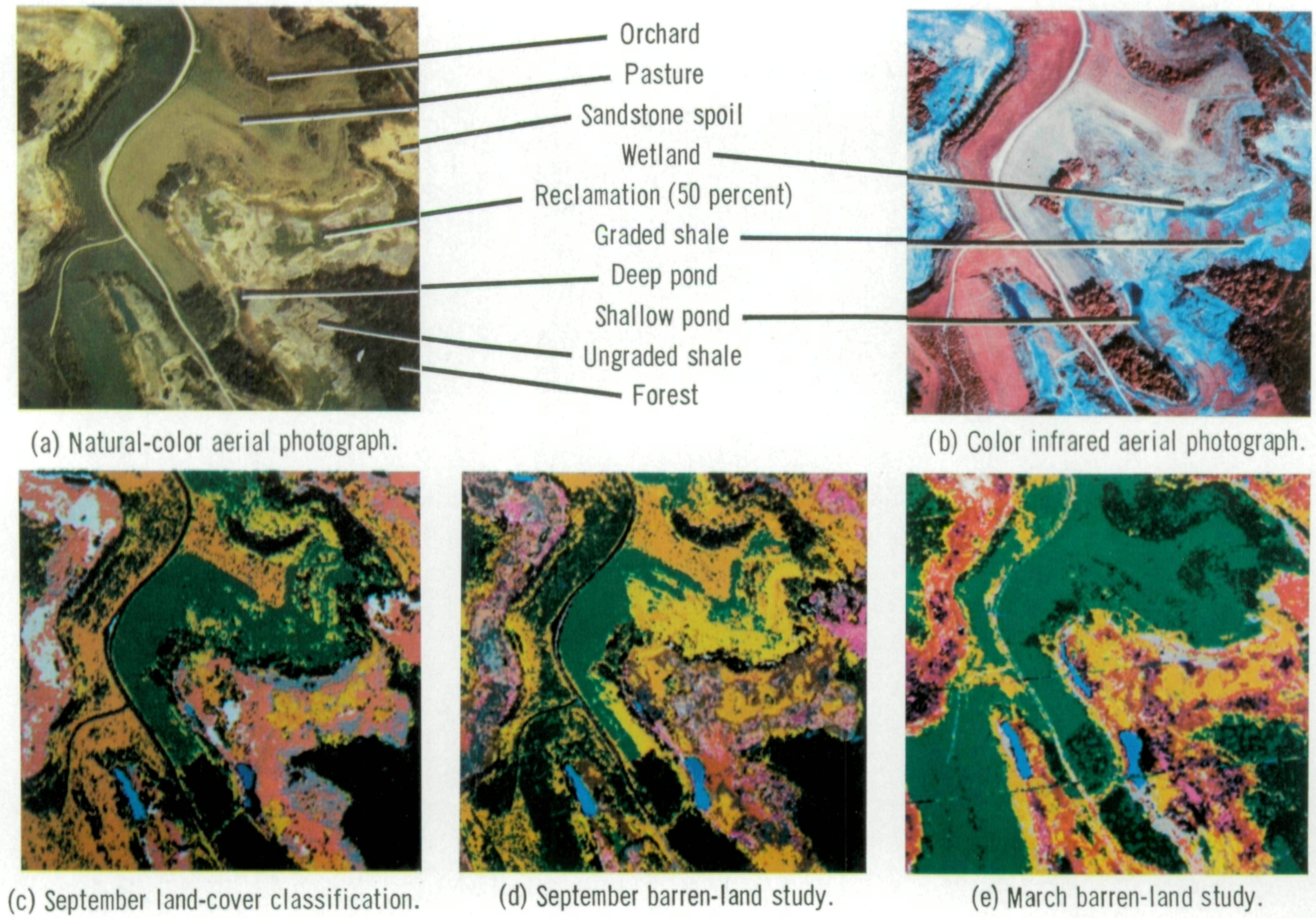
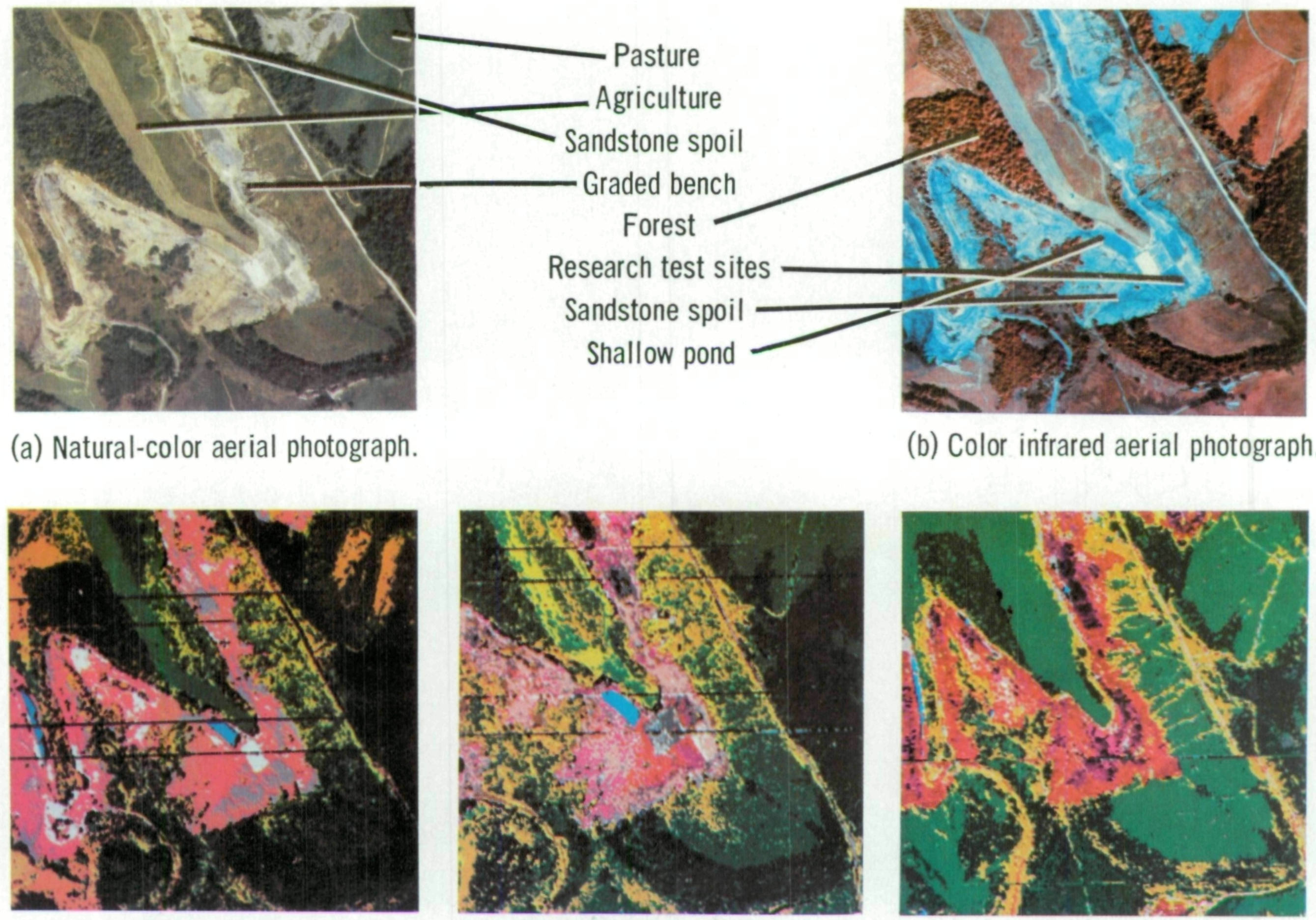


Figure 15. - Subarea 2. Scale factor, approximately 18 000.



(a) Natural-color aerial photograph.

(b) Color infrared aerial photograph.

(c) September land-cover classification.

(d) September barren-land study.

(e) March barren-land study.

Figure 16. - Subarea 3. Scale factor, approximately 18 000.

Figure 17. - Landsat view of test site (MDAS display enlarged 2 times.)

(a) Barren-land presentation of strip-mine area from Landsat band ratio 5/6 data.

Figure 18. - Landsat and LARSYS classification of barren land area. Scale factor, approximately 24 000.

(b) LARSYS classification.

Figure 18. - Concluded.

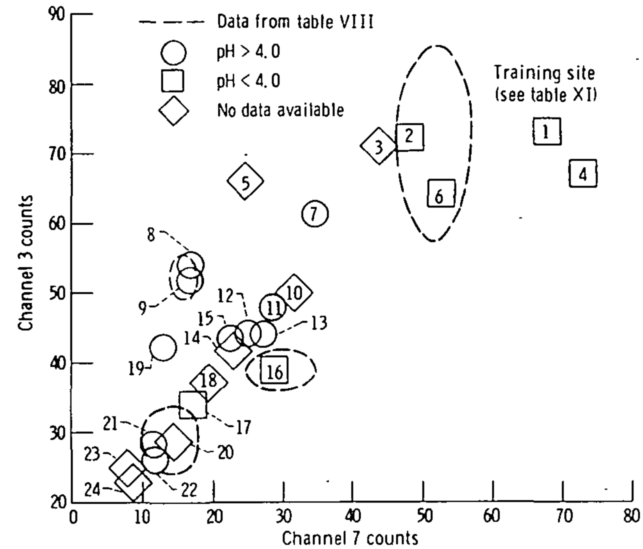


Figure 19. - Sensor data for channels 3 and 7 - September surface-water study. Aircraft altitude, 1.2 kilometers.

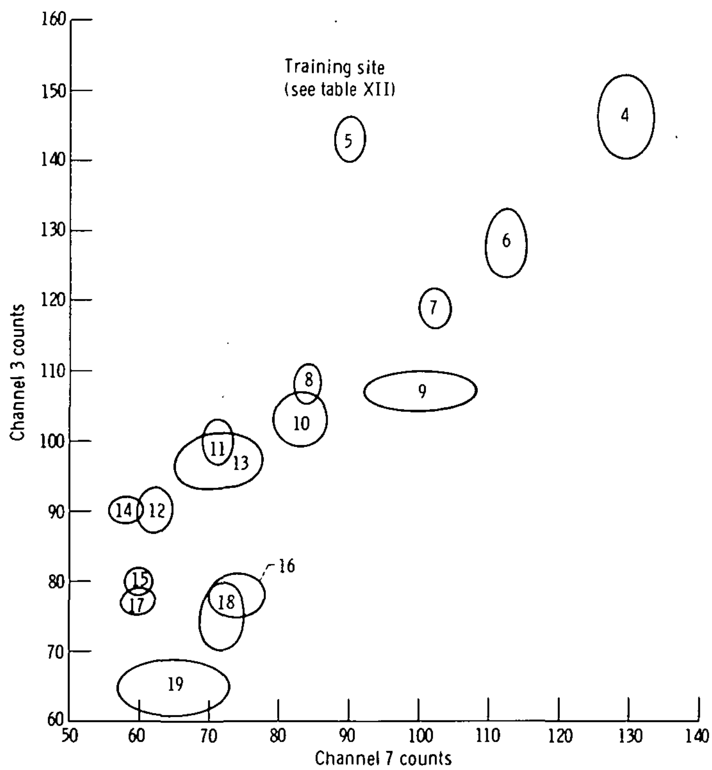
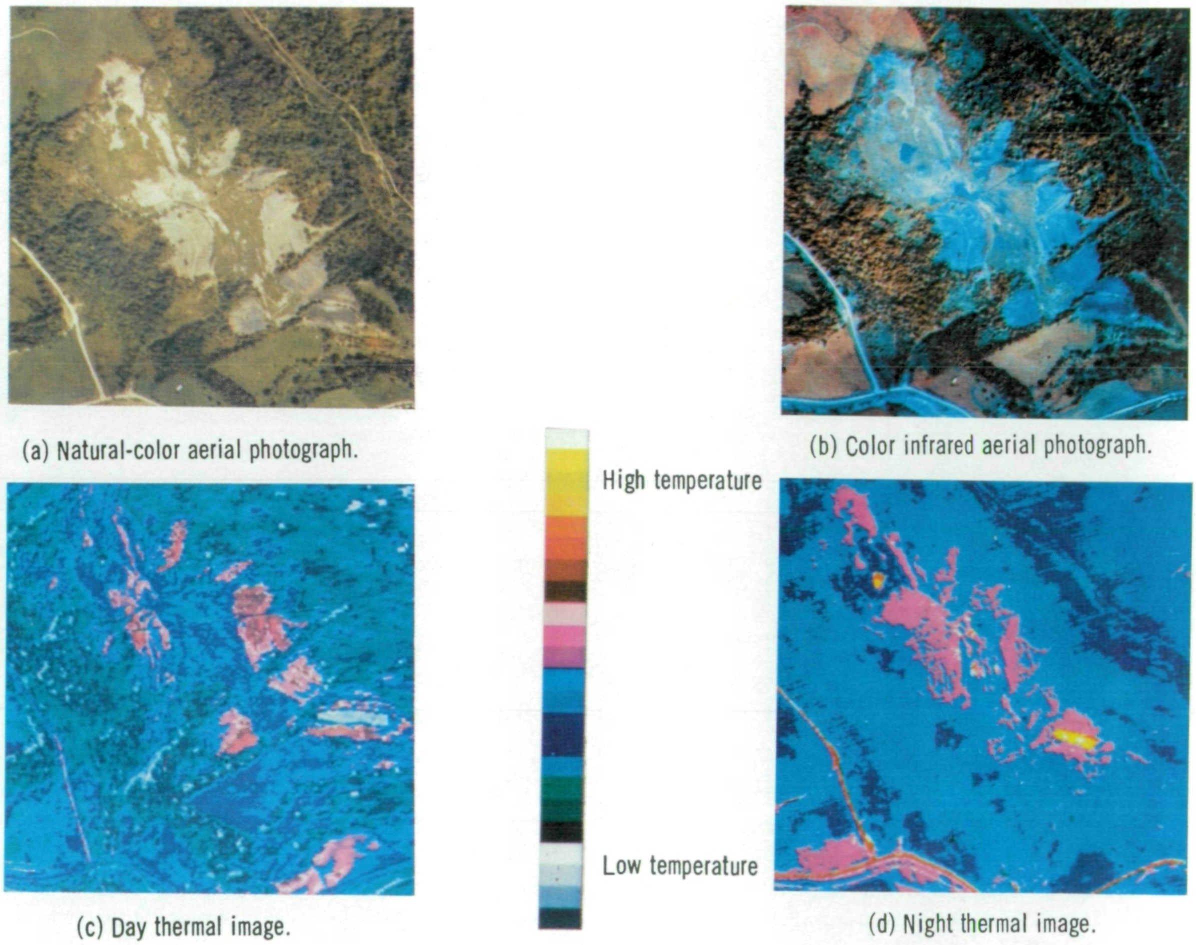


Figure 20. - Sensor data for channels 3 and 7 - March surface-water study. Aircraft altitude, 0.6 kilometer.

(a) Day thermal image.

(b) Night thermal image.

Figure 21. - Thermal images of test site. Scale factor, 24 000.



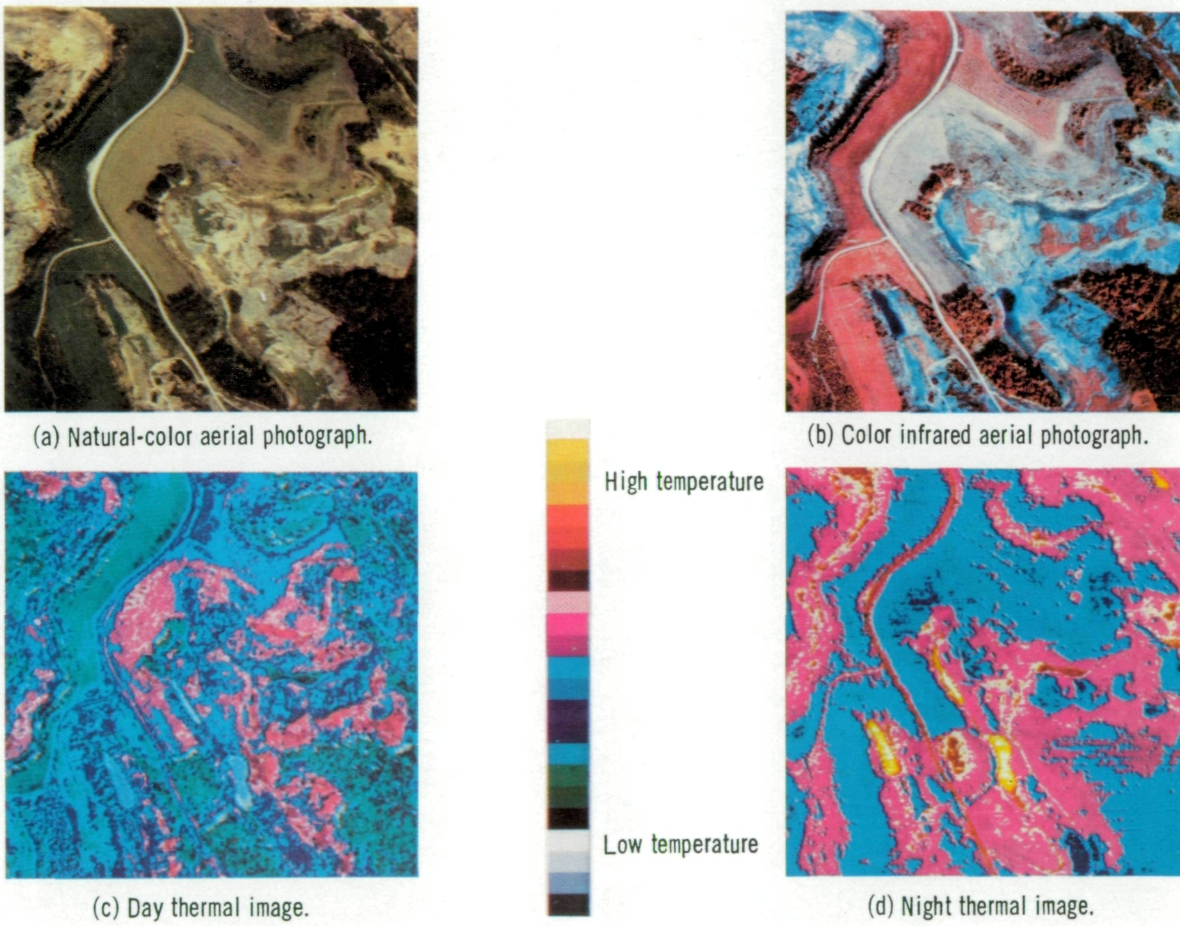
(a) Natural-color aerial photograph.

(b) Color infrared aerial photograph.

(c) Day thermal image.

(d) Night thermal image.

Figure 22. - Thermal images of subarea 1. Scale factor, approximately 18 000.



(a) Natural-color aerial photograph.

(b) Color infrared aerial photograph.

(c) Day thermal image.

(d) Night thermal image.

Figure 23. - Thermal images of subarea 2. Scale factor, approximately 18 000.

Figure 24. - Training-site locations - September land-cover classification. (Training sites 2 and 19 to 22 are not shown).

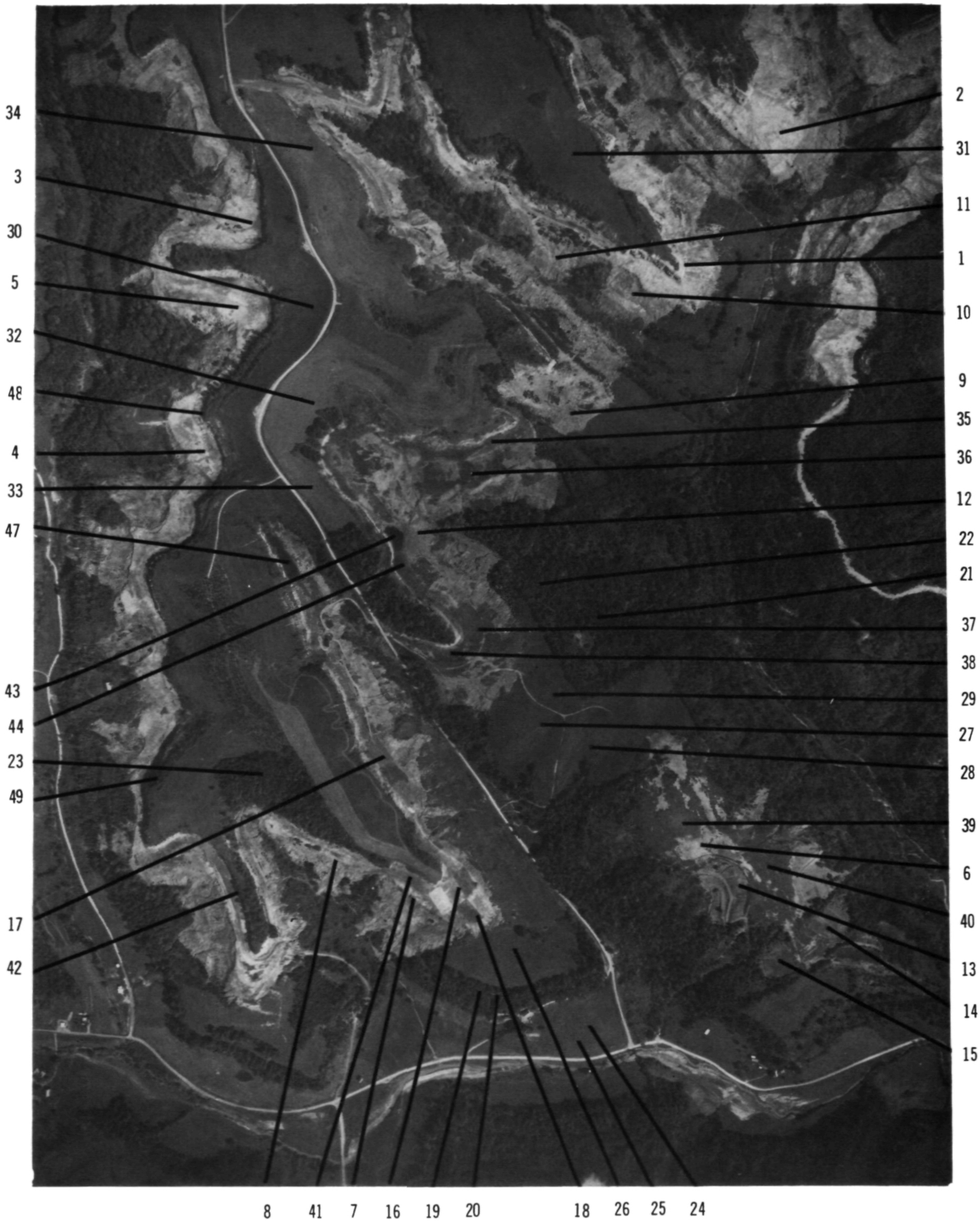


Figure 25. - Training-site locations - September barren-land study. (Training sites 45 and 46 are not included).

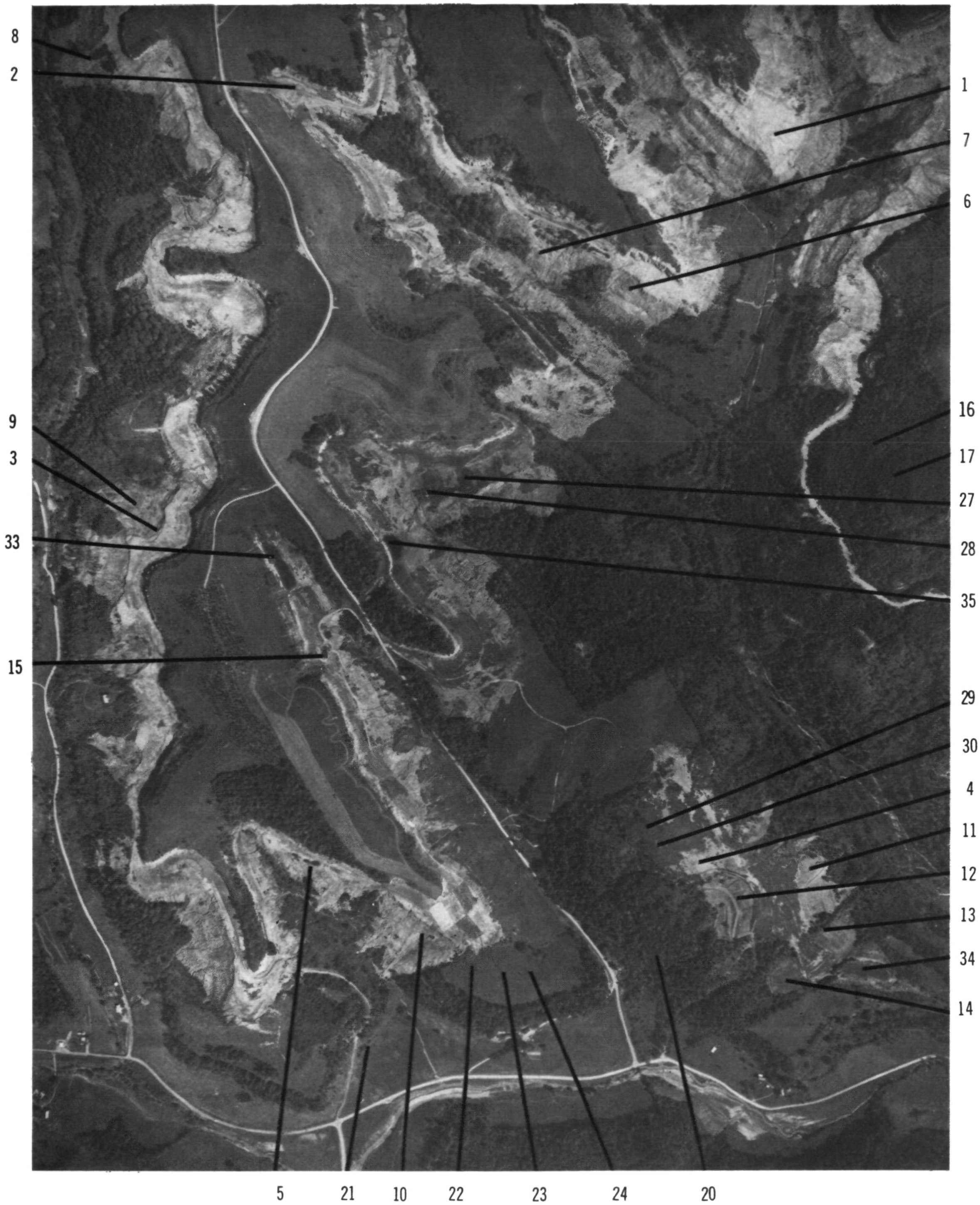


Figure 26. - Training-site locations - March barren-land study. (Training sites 18, 19, 25, 26, 31, and 32 are not included).

Figure 27. - Training-site locations - September surface-water study. (Training sites 1, 3, 5, 10, and 19 are not included).

Figure 27. - Concluded.

Figure 28. - Training-site locations - March surface-water study.

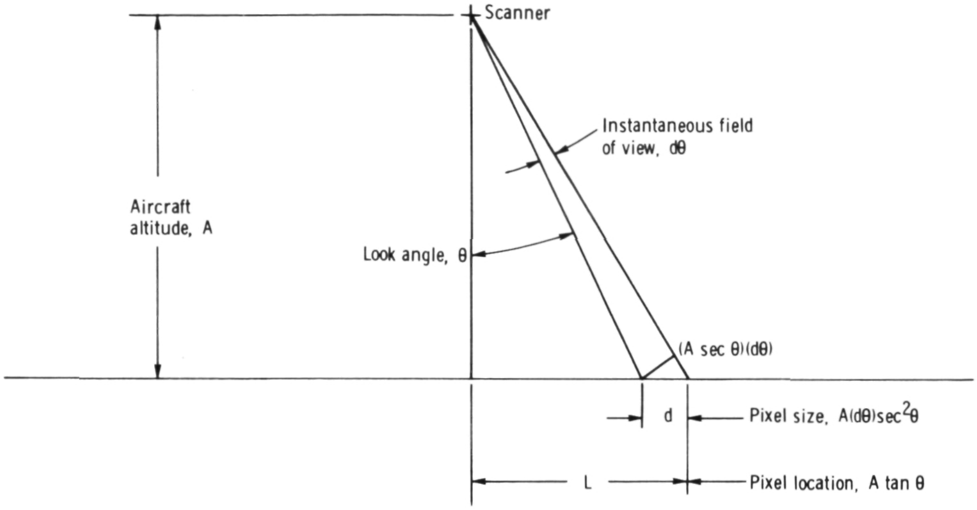


Figure 29. - Scanner view geometry.

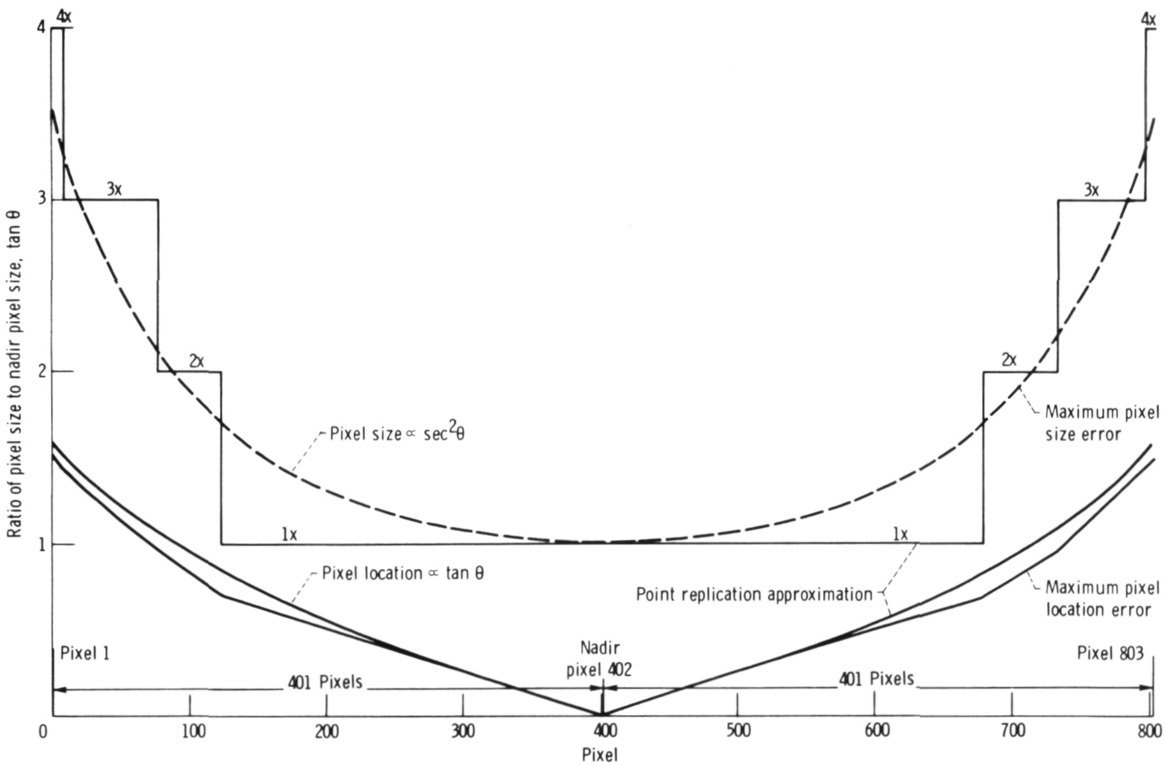


Figure 30. - Image rectification approximation.

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16. Abstract

A study was made to determine the utility of aircraft multispectral scanner data for describing the land-cover features of an abandoned contour-mined coal mine in southeastern Ohio. The data were obtained with an 11-band multispectral scanner aboard an NASA C-47 aircraft at an altitude of 1.2 kilometers. Supervised, maximum-likelihood statistical classifications of the data were made for September and March scenes to establish land-cover classes and also to describe in more detail the barren surface features as they may pertain to the reclamation or restoration of the area. The scanner data for the surface-water areas were studied to establish the variability and range of the spectral signatures. Both day and night thermal images of the area are presented. The results of the study show that a high degree of statistical separation can be obtained from the multispectral scanner data for the various land-cover features, even within thematic categories such as barren land or water, and can be a useful aid for the planning and eventual reclamation of abandoned mines.

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